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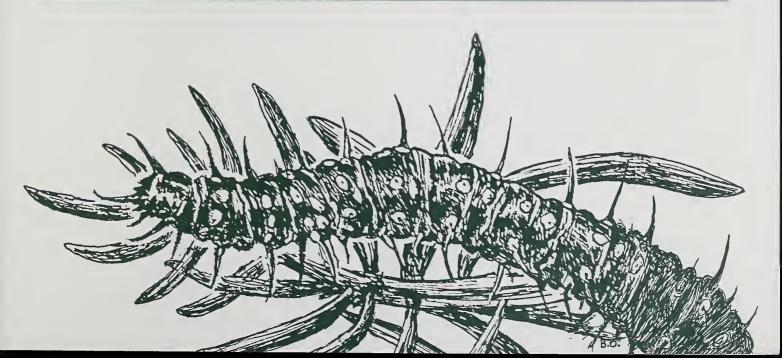Intermountain
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User's Guide to the Western Spruce Budworm Modeling System

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Paul W. Thomas
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$$P(AdultMort) = f_A [foliage]$$

$$Shoot\ Length = \frac{A_1}{1.0 + exp[A_2 + A_3 DDays]}$$

$$Def_{tree} \sim Beta\left(f_B[Def_{class}], f_C[Def_{class}]\right)$$

$$P(Topkill) = \frac{1.0}{1.0 + exp\left[-(b_1 Def_{tree} + b_2 HT_{tree})\right]}$$

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RESEARCH SUMMARY

The Budworm Modeling System is a system of computer programs useful to simulate many aspects of budworm dynamics and budworm-caused damage on stand growth. The *Budworm Dynamics Model* predicts budworm population changes, foliage growth, budworm growth, feeding, and subsequent defoliation dependent on several site, stand, foliage, and weather conditions. A stochastic weather model is used to estimate weather. Measurements of budworm populations, current defoliation, and routine stand examination data comprise the input data. The Budworm Dynamics Model simulates budworm population dynamics on up to thirty stands at a time. Adult dispersal is simulated between stands. Because the model does not estimate tree growth, its use is limited to making short-term (up to 15 years) projections.

The *Prognosis-Budworm Dynamics Model* is a combination of the Budworm Dynamics Model and the Prognosis Model. The Prognosis Model contains tree growth models and is used to estimate stand growth and development. It represents one stand at a time for long-term (about 100 to 300 years) projections. A set of damage models adjusts tree growth, mortality, and top damage to account for budworm-caused defoliation. The Prognosis-Budworm Dynamics Model can be used to make long-term projections of population dynamics, defoliation, and their effects on growth and yield.

Another, smaller, combination of system components is called the *Prognosis-Budworm Damage Model*. It is a combination of the Prognosis Model and the budworm damage components. Estimates of budworm-caused defoliation may be entered directly into this program bypassing the need to run the more complex and expensive dynamics model.

This user's guide describes how to use these computer programs. The scientific basis and behavior of the programs are not included.

ACKNOWLEDGMENTS

The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

CONTENTS

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INTRODUCTION

The Western Spruce Budworm Modeling System

The western spruce budworm (*Choristoneura occidentalis* Freeman) is a defoliator of coniferous forests in Western North America. It is widely distributed and considered an important pest of Douglas-fir, grand fir, white fir, subalpine fir, blue spruce, Engelmann spruce, and some other species (Fellin and Dewey 1982; scientific names are in table 3 under "Using the Prognosis-Budworm Dynamics Model," p. 5).

The Budworm Modeling System is a set of computer programs designed to simulate various components of the budworm and host ecosystem at different temporal and spatial resolutions. There are four computer programs in the system:

1. The **Budworm Dynamics Model** estimates budworm population changes, foliage growth, budworm growth, feeding, and subsequent defoliation dependent on several site, stand, foliage, and weather conditions (Sheehan and others 1987; Sheehan and others 1989). A stochastic weather model is used to simulate weather (Bruhn 1980; Bruhn and others 1979; Kemp and others 1989). Starting site, stand, and foliage data are supplied to the Budworm Dynamics Model by the Prognosis-Budworm Dynamics Model (described below). Measurements of budworm populations, current defoliation, and routine stand examination data are required as data.

The Budworm Dynamics Model simulates budworm population dynamics on up to thirty stands at a time. Adult dispersal is simulated between stands. Because the model does not estimate tree growth, it is useful for making short-term (up to 15 years) projections. Sample trees from a stand are aggregated by host species (and one group for all nonhosts) into one of three height classes. Output consists of several tables describing predicted budworm population dynamics, foliage dynamics, budworm dispersal, and aggregated tree mortality and damage rates.

2. The **Prognosis-Budworm Dynamics Model** is a combination of the Budworm Dynamics Model and the Prognosis Model (Stage 1973; Wykoff 1986; Wykoff and others 1982). When combined with the Prognosis Model in this way, the Budworm Dynamics Model can simulate only one stand at a time but for much longer periods because the Prognosis Model simulates tree growth. This combination can simulate budworm-stand interactions for long time periods. The drawback to this form is that only average net effects of immigration and emigration of budworm in the stand can be simulated.

The Prognosis Model is an individual-tree, distant-independent, stand growth projection model developed first for inland Northern Rocky Mountain forests. This model represents one stand at a time for long-term (about 100 to 300 years) projections. Input consists of a sample-based list of trees that represents the stand. Measurements include tree species, d.b.h., height, crown ratio, past periodic diameter increment, and so on. The sample design and several site characteristics are also required data. Output includes a yield table and other tables describing the species and tree-size composition of the stand.

The Prognosis-Budworm Dynamics Model can be used to make long-term projections of population dynamics and defoliation. A set of damage models adjust tree growth and mortality to account for budworm-caused defoliation. The damage component used in this program is the same damage component used in two programs described next. Using this program, the effects of budworm-caused damage are reflected in growth and yield predictions.

3. The **Prognosis-Budworm Damage Model** is like the Prognosis-Budworm Dynamics Model but does not contain the budworm population dynamics component. It is the smallest program to use as compared to the others that make up the system. You supply estimates of budworm-caused defoliation and the damage components adjust tree growth and mortality appropriately. The estimates of defoliation may be generated using the Budworm Dynamics Model.

4. The **Parallel Processing-Budworm Dynamics Model,** planned for future release, is the last program in the group. It represents the growth of several stands in parallel and is based on the Parallel Processing Extension of the Prognosis Model (Crookston and Stage 1989). This model provides a means for the multistand Budworm Dynamics Model to simulate interactions, including tree growth and insect dispersal between stands, over long time periods. The Parallel Processing-Budworm Dynamics Model will be published as a separate document.

Taken together, these models represent the Budworm Modeling System. The system components are outlined in table 1. Table 2 summarizes how the components are organized into the four computer programs described above.

Content of Guide

This document is a user's guide to the Budworm Modeling System. The model's purpose, general structure, scientific basis, and/or internal programming code are covered in the following publications:

Use of the model in Forest Pest Management decisionmaking	Stage and others (1985)
Use of the model in forest planning	Stage and others (1987)
Budworm Model overview	Sheehan and others (1987)
Budworm Model development	Colbert and others (1983)
Budworm Model scientific basis	Sheehan and others (1989)

Modeling System Applications

Potential applications of the budworm model programs are as follows:

- Exhibit budworm population dynamics within a stand, including the displaying of budworm and foliage phenology, the effects of defoliation, predators, parasites, weather, and dispersal between stands on these dynamics.

- Simulate budworm dynamics in collections of stands that make up management units of forest planning areas (Stage and others 1985, 1987).

- Simulate stand management practices such as thinning and changing species composition to reduce budworm impacts.

- Simulate suppression of budworm populations by direct application of biological or chemical insecticides.

- Simulate the effects of natural enemies on budworm populations and simulate management actions that may enhance the effectiveness of natural enemies in reducing budworm populations.

- Provide the bases for economic analyses of budworm impacts.

- Provide a research tool to design and assist testing alternate hypotheses of biological processes incident to budworm population dynamics.

Table 1—Organization of the Budworm Modeling System components

Component	Task accomplished by the component	Space and time resolution	Relationship to other components
I. Prognosis Model (see Wykoff and others 1982).	Compiles tree inventory, computes normal tree growth and mortality, and reports yield statistics.	One stand for up to 400 years at 10-year intervals.	Estimates of defoliation are provided by either the user or the Budworm Dynamics Model.
II. Linkage			
A. Foliage	Translates tree attributes into foliage and creates Budworm Model tree classes; estimates and reports foliage dynamics; optionally writes a file of foliage statistics.	One stand for up to 15 years at 1-year intervals.	Foliage models are links from the Prognosis Model to the Budworm Models. Produces foliage, the food substrate for the budworm population.
B. Damage	Translates defoliation into reduced growth, topkill, and increased mortality. Reports damage and defoliation statistics.	One stand for up to 15 years at 5-year increments.	Damage models are links from the Budworm Dynamics Model to the Prognosis Model.
III. Budworm			
A. Population dynamics and budworm and foliage phenology	Estimates defoliation, new foliage development, and budworm population dynamics. Is sensitive to varying foliage, site, weather, and budworm control. Reports budworm dynamics.	Up to 30 related stands for up to 15 years using 1-year cycles and 20-degree-day time intervals.	Budworm Dynamics Model estimates defoliation and passes this information to the damage models. It is called after, or uses foliage values from, the foliage models.
B. Weather	Estimates daily precipitation and maximum and minimum temperatures.	Stand on a daily basis.	Called by Budworm Dynamics Model to compute degree days. Drives foliage growth and budworm development.
C. Adult dispersal	One option applies a net dispersal loss or gain.	One stand for up to 15 years by 1-year increments.	Part of the Budworm Dynamics Model that number of adults in each stand.
	Another option computes dispersal from among stands taken together.	Many stands for up to 15 years by 1-year increments.	
IV. Parallel Processing (not documented in this guide).	Controls the running of many stands in parallel within the Prognosis Model.	Many stands for 400 years by 10-year increments.	The Parallel Processing Extension (PPE) calls the Prognosis Model.

Table 2—Organization of system components into the four Budworm Modeling System computer programs

Program name	Included components
Prognosis-Budworm Damage Model	Complete foliage dynamics and tree damage models.
Budworm Dynamics Model	Foliage dynamics models without the components that estimate initial foliage biomass. Tree damage except for components that estimate damage on sample trees. Full population dynamics, weather model, and adult dispersal model.
Prognosis-Budworm Dynamics Model	Complete foliage and tree damage models, complete Budworm Model except for adult dispersal model.
Parallel Processing-Budworm Dynamics Model (use is not documented)	Complete Prognosis-Budworm Dynamics Model, including the adult dispersal model.

COMMON CONCEPTS

Three topics included in this section are important to the understanding or use of any part of the Budworm Modeling System: (1) How trees are represented in the system, (2) how to enter commands, and (3) how to use some commands common to all system comments.

Budworm Model Tree Classes

The Budworm Modeling System represents a stand of trees by storing the number of trees per acre in each of three tree size classes for each host species, plus one class for all nonhost species (tables 3 and 4). This is a different method than used in the Prognosis Model. In the Prognosis Model, critical metrics (d.b.h., height, species, and so on) are stored for up to 1,350 individual sample trees.

The Prognosis Model individual sample trees are classified by the model into the budworm model tree size classes based on tree height. Trees less than 7 m tall are the small trees, medium trees are 7 to 14 m tall, and large trees are those over 14 m tall. In this user's guide, the term "model tree" will refer to a budworm model tree size class.

For each tree size class, the crown is divided into thirds. Therefore, nine crown thirds are defined for each host species (table 3). An overview of how budworm model trees are defined and used in the budworm model can be found in Sheehan and others (1987, 1989).

The foliage in each cell is divided into four age classes as follows: new foliage (current year's growth), 1-year-old foliage, 2-year-old foliage, and the remaining foliage. A system component estimates the amount of biomass in each foliage cell and foliage-age class.

Keyword Structure

The modeling system is controlled using a set of keywords that follow the Prognosis Model keyword format. The keyword field is the first eight columns of the record; the keyword must be left-justified in this field. Seven numeric fields follow; each is 10 columns wide and the first one starts in column 11. Only numbers may be coded in numeric fields or they may be left blank. Blank fields imply that the default for this field is desired; you must enter zeros if you want them. Numeric data should be coded with a decimal and placed anywhere within the field; if the decimal is omitted, you must right-justify the number in the field.

In some cases, more data are needed to implement an option than can be entered in seven fields. In this case, one or more supplemental data records are used. The formats of these vary; they will be described on a case-by-case basis.

When two keywords conflict with each other, the last keyword read applies.

Table 3—Scientific names, common names, species abbreviation, and numeric codes of host tree species used in this document

Scientific name	Common name	Abbreviation	Numeric code[1]
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir	DF	3
Abies grandis (Dougl.) Lindl.	grand fir	GF	4
Abies concolor (Gord. and Glend.) Lindl.	white fir	WF	use grand fir[2]
Abies lasiocarpa (Hook.) Nutt.	subalpine fir	AF	9
Picea engelmannii Parry	Engelmann spruce	ES	8

[1]These numeric codes are the same as those used in the Prognosis Model Inland Empire variant. When using other Prognosis Model variants, use the numeric species codes applicable to the variant.

[2]In some regional variants of the Prognosis Model, white fir is represented. If white fir is represented in the variant you are using, then use the numeric species code for white fir found in the documentation for that variant.

Table 4—Foliage cell (crown third) codes used by the Budworm Modeling System

Tree height size class	Tree class name	Crown third name	Foliage cell numeric code
0-7 m	small	top	1
		middle	2
		bottom	3
7-14 m	medium	top	4
		middle	5
		bottom	6
Over 14 m	large	top	7
		middle	8
		bottom	9

When the Prognosis-Budworm Damage Model or Prognosis-Budworm Dynamics Model is used you must precede all budworm system keywords with the WSBW keyword as described on page 84 of Wykoff and others (1982). The END keyword signals the end of budworm keywords and the continuation of Prognosis Model keywords.

WSBW Signals that budworm model specific keywords follow in the Prognosis Model keyword file.

END Signals the end of budworm model keywords.

File Handling Keywords

File handling can become an important component of preparing a model run. Three keywords are provided to OPEN, CLOSE, and REWIND files. This user's guide provides you with very few guidelines on when or how to use these keywords. If you need help with file handling, consult a person knowledgeable in routine computer use.

OPEN Open the file named on a supplemental record. Note that not all FORTRAN file attributes are supported; some are valid for one operating system and not for another. Regardless of the operating system, the file must be a formatted, sequential file.

On Data General computers (under AOS/VS), the file will be Data Sensitive and "padded" with blanks to a record length of 80 characters unless you specify a different length in field 4 of the keyword record.

On Unisys Series 1100 computers, the maximum record size will default to 80 characters unless you specify a different length in field 4 of the keyword record.

field 1: Data set reference number (or unit) to open; no default.

field 2: Enter a nonzero value if blanks in the data set are to be treated as NULL characters. Enter a blank field or a zero (which is the default) to signify that blanks be treated as zeros when the file is read for numeric data.

field 3: Enter a code for the file status: 0 (or leave the field blank) for UNKNOWN, 1 for NEW, and a 2 for OLD.

field 4: The MAXRECL parameter for Data General computers or the MRECL parameter on Unisys computers; default is 80 characters.

Supplemental data record:

Cols 1-40: Enter the data set name with no leading blanks.

CLOSE field 1: Data set reference number to close; no default, an entry is required.

REWIND field 1: Data set reference number to rewind; no default, an entry is required.

Entering Comments

Comments can be entered into a keyword file using the COMMENT keyword. All of the records that follow the COMMENT keyword are treated as a comment up to a record that contains "END" in the first 3 columns.

COMMENT Enter comments on supplemental data records that follow this keyword. END the comments with a record that contains END in the first 3 columns.

Random Number Generator

Some components of the Budworm Modeling System use random numbers to represent random processes or unexplained variation. The Budworm Dynamics Model uses the weather model to generate daily maximum and minimum temperatures. The weather model contains a random number generator that is used in simulating weather. The tree damage components use a random number generator when computing the effects of defoliation on individual tree growth, topkill, and mortality. You can reseed the budworm model random number generator using the RANNSEED keyword.

RANNSEED field 1: New random number generator seed, default = 55329. If you enter 0.0, a seed will be generated by calling the computer system clock.

USING THE PROGNOSIS-BUDWORM DAMAGE MODEL

The Prognosis-Budworm Damage Model can be used to estimate growth and yield given defoliation values you specify. You must prescribe the amount of defoliation by year, host species, foliage cell, and foliage age class, rather than using the Budworm Dynamics Model to generate these estimates of defoliation automatically.

Entering Defoliation Estimates

Defoliation data are entered using the DEFOL keyword. You can enter several DEFOL keywords for any one year, and for as many years as you wish. The model applies the defoliation to the budworm model trees and estimates the appropriate growth. Crookston (1985) has described this use of the DEFOL keyword. The

DEFOL keyword is only used to enter annual defoliation values. Defoliation of 1-year-old and older foliage implies that budworms feed on old foliage by "back-feeding" during the current year. Defoliation from the previous year is not entered using this keyword.

Use the SETPRBIO keyword to enter inventory-time estimates of the proportion of retained biomass for the 1-year-old, 2-year-old, and remaining foliage classes. These estimates are proportional to the normal biomass of healthy, nondefoliated trees. They are applicable regardless of how many or which years the observed defoliation occurred. This option results in a lower resolution accounting for previous defoliation than is possible using the DEFOL keyword.

DEFOL Enter defoliation by year, host species, crown third level (foliage cell), and foliage age class.

field 1: The year of defoliation; default is 1.

field 2: Numeric species code, see table 3; default is all host species.

field 3: Foliage cell numeric code from table 4; in addition code 10 may be used to signify all foliage cells in small trees, code 11 for medium trees, code 12 for large trees, code 13 for the tops of all tree sizes, code 14 for middle crowns, code 15 for the bottom crowns. Default is all foliage cells.

field 4: Percent new foliage defoliated; default = 0 percent.

field 5: Percent 1-year-old foliage defoliated; default = 0 percent.

field 6: Percent 2-year-old foliage defoliated; default = 0 percent.

field 7: Percent remaining (3 years and older) foliage defoliated; default = 0 percent.

SETPRBIO Set the proportion of retained biomass to an inventory time estimate. The data entered using SETPRBIO are used to alter the starting foliage biomass values.

field 1: The year that the SETPRBIO is applied; default is year 1.

field 2: Numeric species code, see table 3; default is all host species.

field 3: Foliage cell numeric code from table 4; in addition code 10 may be used to signify all foliage cells in small trees, code 11 for medium trees, code 12 for large trees, code 13 for the tops of all tree sizes, code 14 for middle crowns, code 15 for the bottom crowns. Default is all foliage cells.

field 4: Proportion of 1-year-old foliage retained; default is 1.0 which means 100 percent of the foliage you expected was retained (entering 0.6 means that 40 percent of the foliage was missing).

field 5: Proportion of 2-year-old foliage retained; default is 1.0.

field 6: Proportion of remaining foliage retained; default is 1.0. Entering 2.0 means that twice as much foliage is in the remaining age class than you would expect on a healthy tree and implies that the trees responded to defoliation by retaining old needles.

7

Example 1: Using DEFOL and SETPRBIO—You have a 2-year-old inventory of trees and defoliation estimates for a stand. You desire to make a 30-year-long projection of stand development that is sensitive to the defoliation recorded at tree inventory time for each of the past 2 years, and estimated for the next 4 years. SETPRBIO is used to enter the inventory-time estimates of defoliation that occurred the past 2 years, and DEFOL keywords are used to enter estimates for the next 4 years.

Reference line	Keyword	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7
1	INVYEAR	1986.						
2	NUMCYCLE	3.						
3	NOCALIB							
4	WSBW							
5	SETPRBIO	1986.	3.		.4	.2	.8	
6	SETPRBIO	1986.	3.	1.	.2	.0	.4	
7	DEFOL	1986.	3.	1.	80.	20.		
8	DEFOL	1986.	3.	2.	70.	10.		
9	DEFOL	1986.	3.	3.	60.			
10	DEFOL	1986.	3.	4.	60.			
11	DEFOL	1986.	3.	5.	50.			
12	DEFOL	1986.	3.	6.	40.			
13	DEFOL	1986.	3.	7.	60.			
14	DEFOL	1986.	3.	8.	50.			
15	DEFOL	1986.	3.	9.	40.			
16	DEFOL	1987.	3.	1.	100.	80.	80.	50.
17	DEFOL	1987.	3.	2.	100.	80.	70.	40.
18	DEFOL	1987.	3.	3.	100.	70.	60.	30.
19	DEFOL	1987.	3.	4.	100.	80.	60.	20.
20	DEFOL	1987.	3.	5.	80.	60.	40.	10.
21	DEFOL	1987.	3.	6.	60.	50.	20.	
22	DEFOL	1987.	3.	7.	60.	40.	20.	
23	DEFOL	1987.	3.	8.	40.	20.	20.	
24	DEFOL	1987.	3.	9.	30.	10.	10.	
25	DEFOL	1988.	3.	1.	30.			
26	DEFOL	1988.	3.	2.	10.			
27	DEFOL	1988.	3.	4.	30.			
28	DEFOL	1988.	3.	5.	10.			
29	DEFOL	1988.	3.	7.	10.			
30	DEFOL	1989.	3.	1.	20.			
31	DEFOL	1989.	3.	2.	20.			
32	END							
33	PROCESS							

Lines 1-2: Enter the inventory year and the length of the projection.

Line 3: The run is made using the NOCALIB option, because previous damage would have already reduced growth rates on the inventoried trees. Adjusting the Prognosis Model to these growth rates (which would happen if NOCALIB is not specified) and then reducing growth even more to account for budworm damage would result in double counting of damage.

Line 4: Signals that Budworm Model keywords follow.

Lines 5-6: The first SETPRBIO keyword specifies that 0.4 of the 1-year-old foliage, 0.2 of the 2-year-old foliage, and 0.8 of the remaining foliage biomass remained on all foliage cells of Douglas-fir hosts. The second SETPRBIO keyword changes the values for the tops of the small Douglas-fir trees to 0.2, 0.0, and 0.4 for the 1-year-old, 2-year-old, and remaining foliage classes. The proportion-of-remaining-foliage values are used to adjust the inventory-time foliage profile.

8

Lines 7-31: DEFOL keywords apply annual defoliation values. The damage models will estimate damage that results from defoliation occurring in 1986-89, inclusively.

Line 32: Signal the end of Budworm Model keywords.

Lines 33-34: Process the stand and stop.

The Prognosis Model's Activity Schedule

The Prognosis Model produces an Activity Summary Table (see figure 9, page 37, Wykoff and others 1982) that describes the activities as actually invoked. Details of how the model schedules activities are hard to remember. Review this table to ensure that the model accomplished what you intended.

Representing Management Actions

You can use the Prognosis-Budworm Damage Model to represent direct suppression of budworms and silvicultural manipulation of stand structure. Direct suppression is simulated by running the model once with a set of DEFOL keywords that represent the defoliation you expect without spraying and once with a different set that represents the defoliation you expect when spraying is applied. The difference between the projected outcomes can be interpreted as the gain (or loss) due to applying the spray. Note that you must provide the DEFOL keywords that reflect estimated defoliation sequences with and without spraying. The assumptions you make in preparing the DEFOL keywords are critical to the integrity of the model predictions.

Silvicultural treatments are simulated using the Prognosis Model thinning options. Thinnings are simulated by the Prognosis Model at the beginning of model cycles; not during cycles. For example, say you want to simulate removal of the pole-sized and smaller Douglas-fir from a stand containing ponderosa pine and Douglas-fir. You wish to simulate the removal in year 1995. You must ensure that a Prognosis Model cycle boundary occurs in year 1995 or else the model will change the thinning year to coincide with the cycle boundary. If the cycle boundary years are 1990 and 2000, the thinning would be simulated in 1990. Use the Prognosis Model TIMEINT and NUMCYCLE keywords to control the model's cycling logic.

Suppressing Topkill Calculations

Budworm-caused damage to trees is calculated when the Prognosis-Budworm Damage Model is used. Reduction in tree growth rates, increased tree mortality rates, and top damage are simulated. The Prognosis Model contains a set of options that allow you to simulate top damage. If you use those options, you may wish to stop the Prognosis-Budworm Damage Model from estimating top damage.

TOPKILL   Activate the Prognosis-Budworm Model's topkill logic (the
NOTOPKILL   default); or turn it off.

Writing a Foliage File

An inventory of trees can be translated into Budworm Dynamics Model input using a Prognosis-Budworm Damage Model keyword called WRITEFOL. The Budworm Dynamics Model can read this file as a description of the stand. The foliage file contains all of the site, stand, and foliage statistics needed to run the Budworm Dynamics Model separately from the Prognosis Model. It also contains the stand identification, run title, and management code specified using the Prognosis Model keywords STANDID and MGMTID. The year of the inventory (or the year specified on the WRITEFOL keyword, see below) is also written and is the default starting year for the Budworm Model projection. The WRITEFOL operation is executed only at the beginning of Prognosis Model cycles; therefore, any WRITEFOL scheduled for the middle of a cycle will occur at the beginning of that cycle.

The data are written in 80-column format (the first column is always blank), and the file may be examined and edited; however, this file is not intended to be edited or studied. It is organized for ease of data transfer between programs. See appendix B (table B-2, page 58) for a detailed description of the file's contents.

9

WRITEFOL   Requests that a file of budworm model foliage conditions be written for the stand.

field 1:   The year during the projection that the file is to be written. Default = 1. You may enter any year greater than or equal to the inventory year and prior to the end of the projection. Several WRITEFOL keywords may be entered for different years; each will result in an additional file.

field 2:   The data set reference number (also called a logical unit number) for the file. No entry results in data being printed with other budworm model output. The WRITEFOL keyword does not open a file for output. You must use the OPEN keyword or some other means to ensure that the referenced file can be written.

Example 2: Using WRITEFOL—You may use the Prognosis-Budworm Damage Model to process tree inventory data for a stand. The growth and development of the stand can be projected from the inventory year (1986, for example) up to the current year (1990), and the foliage values written to a file (data set reference number 20). For simplicity, default Prognosis Model options are used whenever possible.

Reference line	Keyword	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7
1	INVYEAR	1986.						
2	NUMCYCLE	1.						
3	TIMEINT	1.	4.					
4	WSBW							
5	OPEN	20.						
6	MYSTAND.WRITEFOL							
7	WRITEFOL	1990.	20.					
8	END							
9	PROCESS							
10	STOP							

Lines 1-3: Specify the inventory year, the number of cycles, and the length of the first cycle.

Line 4: Signal that budworm model options follow.

Lines 5-6: Open a file called MYSTAND.WRITEFOL and reference it with data set reference number 20.

Line 7: Schedule the foliage and other stand statistics to be written on a file referenced by the number 20 and that they will represent the stand as it is in year 1990.

Line 8: Signal the end of budworm model keywords.

Lines 9-10: Process the stand and STOP.

The Prognosis Model keywords for other stands could follow; each would contain the keywords for the WRITEFOL option. After your foliage file is complete, you can enter the data into the Budworm Model using the READFOL option described in the section titled "Using the Budworm Model."

You can use the DEFOL keyword to adjust the foliage values to account for current defoliation before using the WRITEFOL keyword. Let's revisit example 2 to illustrate this case. If budworms had defoliated the stand between 1986 and 1990, and if you had measured the annual defoliation for each of these years, you could enter the defoliation values using the DEFOL keyword. You would also enter the WRITEFOL keyword for 1990 as was done in example 2.

USING THE PROGNOSIS-BUDWORM DYNAMICS MODEL

The Prognosis-Budworm Dynamics Model is a combination of the Prognosis-Budworm Damage Model and the Budworm Dynamics Model (table 2). This model predicts defoliation based on a detailed simulation of budworm population dynamics.

Calling the Budworm Dynamics Model

The CALLBW keyword is used to schedule a call to the Budworm Dynamics Model from the Prognosis Model. Note that a CALLBW keyword is used in place of DEFOL keywords; if both CALLBW and DEFOL keywords are scheduled for the same Prognosis Model cycle, the CALLBW keyword is canceled by the model. SETPRBIO and WRITEFOL keywords can be scheduled for the same cycle as CALLBW.

You can schedule the Budworm Dynamics Model to run for several different time periods. For example, you may enter a CALLBW for year 1990, and another for year 2030. If the Prognosis Model cycle boundaries do not coincide with 1990 and 2030, CALLBW's will be moved by the model so that they coincide with cycle boundaries.

In some rare cases one or more CALLBW keywords may be canceled by the model. One such case was described above: DEFOL and CALLBW keywords cannot be simulated in the same cycle. Another case involves overlapping two CALLBW keywords. For example, say one CALLBW keyword was scheduled for year 1990 and another for year 2000. Furthermore, say that the one scheduled for 1990 was set up to run for 15 years. In this case the second CALLBW, scheduled for 2000, would be canceled.

CALLBW   Schedule a call to the Budworm Dynamics Model. Several CALLBW keywords may exist for one projection; however, you need only specify one for a budworm projection even if it is scheduled to last longer than the length of a cycle.

field 1:   Year the Budworm Dynamics Model is called; default = 1.

field 2:   The number of years the model will run; default = 10.

Using the Weather Model

The Weather Model provides estimates of daily weather to the Budworm Dynamics Model. A separate user's guide (Kemp and others 1989) describes how to control the options within the Weather Model. Here we introduce two keywords: WEATHER transfers control to the Weather Model so that it can read its own options, and END returns control to the Budworm Dynamics Model. Note that the WEATHER keyword must be placed inside a WSBW-END keyword group when using the Prognosis-Budworm Dynamics Model.

WEATHER   Signals Weather Model keywords follow.

END   Signals the end of Weather Model keywords.

Example 3: CALLBW and Select a Weather Station—In the following keyword file, a call to the Budworm Dynamics Model is scheduled for the year 1990 and a Weather Model keyword called USESTA (see Kemp and others 1989) is used to select a weather station. Control is then returned to the Prognosis Model.

Reference line	Keyword	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7
1	INVYEAR	1986.						
2	NUMCYCLE	3.						
3	TIMEINT	1.	4.					
4	WSBW							
5	CALLBW	1990.	20.					
6	WEATHER							
7	USESTA	2.						
8	END							
9	END							
10	PROCESS							
11	STOP							

Lines 1-2: Set the inventory year to 1986 and the number of cycles to 3.

Line 3: Set the length of the first cycle to 4 years so that the beginning of the second cycle will be 1990.

Line 4: Signal that Budworm Dynamics Model keywords follow.

Line 5: Schedule a call to the Budworm Dynamics Model in year 1990 and specify that the model will run a maximum of years (20 years).

Line 6: Signal that Weather Model keywords will follow. Note that this keyword cannot be entered before line 4 or after line 9 because it is recognized by the Budworm Dynamics Model and not by the Prognosis Model.

Lines 7-8: Set the internal station number to station 2 and END the Weather Model keywords. See Kemp and others (1989) for a description of the USESTA keyword.

Line 9: Signal the END of Budworm Dynamics Model keywords.

Line 10-11: Process the stand and stop.

The Budworm Dynamics Model contains many keywords that control output and several biological components of the model. The next section explains the output produced and how to request it. Following the output section, several additional keywords are described that apply to the Budworm Dynamics Model. You may use most of these keywords (the few exceptions are covered when they are presented) in the Prognosis-Budworm Dynamics Model.

OUTPUT

Output generated by the budworm model components is basically the same whether or not it is linked to the Prognosis Model. However, some of the output is specific to a model component. For example, populations dynamics component outputs information concerning budworm population dynamics. If you are not using the dynamics model, this output is not available. On the other hand, if you are using the Budworm Dynamics Model without it being linked to the Prognosis Model, then only relative damage can be output. Statistics on absolute damage requires that the Prognosis Model be linked.

The following text describes the output tables that are available from the complete system. System programs that generate the output are identified. All of the output tables except the Keyword Table (described in the next section) are optional. You must enter the appropriate keyword to request that it be printed. Not printing the output is the default in all cases.

Most of the output that is presented in the following tables can be produced in machine-readable format. See the description of the STATDATA keyword on page 21 and in appendix B, page 56, for a description of this output.

Keyword Table

The Options Selected by Input table for a Budworm Dynamics Model run is illustrated in figure 1. If you are using a version that is linked to the Prognosis Model, similar information is displayed inside Prognosis Model's options table. The left-hand side of this table contains the keywords entered to control the model. The main body of the table is text describing the effects of the keywords and a list of the keyword parameters as they have been interpreted. Default values are displayed for fields left blank. Other informational messages are often output in this table.

Initial Conditions

The Budworm Dynamics Model can produce a table that describes the initial conditions for each stand (fig. 2). The number of model trees per hectare, the actual sizes of the trees, the amount of biomass, and the number of eggs and egg density are displayed. The stand elevation and seral stage code (Sheehan and others 1989)

```
         WESTERN SPRUCE BUDWORM MODEL        VERSION  3.00     08-16-1990  16:09:34

-------------------------------------------------------------------------------------------
                                OPTIONS SELECTED BY INPUT
-------------------------------------------------------------------------------------------
KEYWORD    PARAMETERS:
--------   --------------------------------------------------------------------------------
STNDLOCS   STAND AREAS AND LOCATIONS READ FROM DATA SET REFERENCED BY NUMBER=  15
           4 RECORDS WERE PROCESSED.

FLYUNIT    SIMULATE DISPERSAL BETWEEN STANDS.

ADDSTAND   READ STAND IDENTIFIERS AND FOLIAGE VALUES FROM THE DATA SET REFERENCED BY NUMBER   22

           STAND NUMBER=   1  STAND IDENT=BEAR01    MANAGEMENT ID=NONE
           RUN TITLE=West end of Bear Gulch, Malheur National Forest, Oregon.

END        END OF THIS STANDS OPTIONS.

ADDSTAND   READ STAND IDENTIFIERS AND FOLIAGE VALUES FROM THE DATA SET REFERENCED BY NUMBER   22

           STAND NUMBER=   2  STAND IDENT=BEAR02    MANAGEMENT ID=NONE
           RUN TITLE=Middle of Bear Gulch, Malheur National Forest, Oregon

END        END OF THIS STANDS OPTIONS.

ADDSTAND   READ STAND IDENTIFIERS AND FOLIAGE VALUES FROM THE DATA SET REFERENCED BY NUMBER   22

           STAND NUMBER=   3  STAND IDENT=BEAR03    MANAGEMENT ID=NONE
           RUN TITLE=East end of Bear Gulch, Malheur National Forest, Oregon.

END        END OF THIS STANDS OPTIONS.

PROJECT    THERE ARE  3 STANDS IN THIS PROJECTION.  YEARS ARE: 1986 TO 1988
-------------------------------------------------------------------------------------------
```

Figure 1—The options a user selects comprise the first table produced.

```
              WESTERN SPRUCE BUDWORM MODEL        VERSION  3.00     08-16-1990  16:09:35

   PROCESSING:  YEAR= 1986; STAND NO=  1; STAND ID= BEAR01  ; MANAGEMENT ID= NONE

   INCOND: BUDWORM HABITAT CODE=   1; STAND ELEVATION (METERS)= 1554.; SERAL LIFE STAGE=  2.13

                       MODEL    CELL              TOTAL      NEW                          EGG
                BW     TREES  MIDPOINT   CELL    ADJUSTED  ADJUSTED                       MASS
              TREE  CROWN  PER   HEIGHT  LENGTH   BIOMASS   BIOMASS  POTENTIAL    EGGS  DENSITY
     HOST  SIZE  THIRD  HECTARE (METERS) (METERS) (GRAMS)   (GRAMS)  FOLIAGE     PER    (EM/M2)
                                                                      (M2)      CELL
     ----  ----  -----  ------- -------- -------- --------  -------- ---------  ----   -------
     DF   SMALL   TOP             2.55    0.85     27.06     18.94     0.07     22.63    8.65
     DF   SMALL MIDDLE            1.69    0.85    162.33     73.05     0.40     87.95    6.00
     DF   SMALL BOTTOM            0.84    0.85    351.72    123.10     0.92    101.48    3.00
     DF   SMALL   TREE  370.65                    541.11    215.09     1.38    212.06    3.82

     DF   MEDIUM   TOP            7.96    1.61    478.41    239.20     1.25    344.58    7.45
     DF   MEDIUM MIDDLE           6.36    1.61   1435.22    430.57     3.51    647.99    5.00
     DF   MEDIUM BOTTOM           4.75    1.61   1275.75    127.57     3.32    337.42    2.75
     DF   MEDIUM   TREE  612.52                  3189.37    797.34     8.08   1329.99    4.10

     DF   LARGE    TOP           15.74    3.08   3725.98   1862.99     9.75   7510.83   20.85
     DF   LARGE  MIDDLE          12.67    3.08  11177.96   3353.39    27.33  13373.93   13.25
     DF   LARGE  BOTTOM           9.59    3.08   9935.96    993.60    25.87   9269.46    9.70
     DF   LARGE    TREE  228.53                 24839.90   6209.98    62.96  30154.21   11.94

     DF   AVERAGE  TREE                          6462.62   1640.07    16.38   6424.34    9.78

     STD  AVERAGE  TREE                          6462.62   1640.07    16.38   6424.34    9.78
```

Figure 2—The initial conditions table is generated when the INCOND keyword is specified. Note the message line starting with the word "PROCESSING". This line is printed regardless of which output you request.

13

are displayed at the top of the table. Use the INCOND keyword to request this table. This keyword is not available using the Prognosis-Budworm Damage Model.

INCOND   Request that the initial conditions be displayed.
NOINCOND

Foliage

Two tables display foliage statistics. The first, the foliage summary or FOLSUM table (fig. 3), displays the amount of foliage in each crown third of each host. The second table is the detailed foliage summary, called DETFOL. FOLSUM is available from all modeling system programs; DETFOL is not available when using the Prognosis-Budworm Damage Model.

The FOLSUM table is printed at the beginning of a year (SPRG) and in the FALL (indicated by the FALL in the upper left-hand corner of the table illustrated in fig. 3). There are four lines for each budworm model tree class. The first is for the TOP crown third, the second for the middle (MID) crown third, and the third line for the bottom (BOT) crown third. There is a fourth line for the tree as a whole. If there are no trees in a size class, the lines for that class are not printed. After each tree class of a host species is listed, an additional line is printed for the average tree of that host species. The average is weighted by the number of trees per hectare represented by each model tree. A report of the host totals weighted by budworm trees per hectare is also generated under the host label TOT.

There are three columns that identify host, tree, and crown class, and 11 more columns that identify the foliage statistics. These 11 columns are grouped into five groups. The first group, NEW FOLIAGE, has three attributes. They are:

SUMMER   This quantity is new foliage biomass (grams) in midsummer.
BIOMASS   When the table is labeled SPRG for spring conditions, the SUM-MER BIOMASS is interpreted as the amount of biomass that would be on the tree by midsummer given no budworm defoliation. The NEW FOLIAGE SUMMER BIOMASS is converted into a number of buds in the budworm model, and the foliage phenology models predict the rate at which the buds develop. If there is no defoliation, the buds will form the biomass reported here as SUMMER

FOLSUM 1986 HOST	FALL TREE SIZE	 CROWN LEVEL	------- NEW FOLIAGE -------			---- 1-YR-OLD ----		---- 2-YR-OLD ----		---- REMAINING ---		---- TOTALS -----	
			SUMMER BIOMASS (G)	 % OF ADJUSTED	ADJUSTED POTENTIAL (G)	SUMMER BIOMASS (G)	ADJUSTED POTENTIAL (G)	SUMMER BIOMASS (G)	ADJUSTED POTENTIAL (G)	SUMMER BIOMASS (G)	ADJUSTED POTENTIAL (G)	SUMMER BIOMASS (G)	ADJUSTED POTENTIAL (G)
DF	SMALL	TOP	6.1	67.724	18.9	6.5	6.5	1.1	1.1	0.5	0.5	14.2	27.1
DF	SMALL	MID	39.5	45.894	73.0	48.7	48.7	32.5	32.5	8.1	8.1	128.8	162.3
DF	SMALL	BOT	63.3	48.542	123.1	105.5	105.5	87.9	87.9	35.2	35.2	292.0	351.7
DF	SMALL	TREE	109.0	49.332	215.1	160.7	160.7	121.5	121.5	43.8	43.8	435.0	541.1
DF	MEDIUM	TOP	84.4	64.733	239.2	167.4	167.4	57.4	57.4	14.4	14.4	323.6	478.4
DF	MEDIUM	MID	12.1	97.198	430.6	358.8	358.8	287.0	287.0	358.8	358.8	1016.7	1435.2
DF	MEDIUM	BOT	0.0	100.000	127.6	41.5	255.1	255.1	255.1	637.9	637.9	934.5	1275.7
DF	MEDIUM	TREE	96.4	87.907	797.3	567.7	781.4	599.6	599.6	1011.0	1011.0	2274.8	3189.4
DF	LARGE	TOP	760.1	59.200	1863.0	1117.8	1117.8	558.9	558.9	186.3	186.3	2623.1	3726.0
DF	LARGE	MID	1314.3	60.806	3353.4	2794.5	2794.5	2235.6	2235.6	2794.5	2794.5	9138.9	11178.0
DF	LARGE	BOT	0.0	100.000	993.6	1900.6	1987.2	1987.2	1987.2	4968.0	4968.0	8855.7	9936.0
DF	LARGE	TREE	2074.4	66.595	6210.0	5812.8	5899.5	4781.7	4781.7	7948.8	7948.8	20617.7	24839.9
DF	AVERAGE	TOP	187.9	60.703	478.1	297.4	297.4	134.8	134.8	42.6	42.6	662.6	952.8
DF	AVERAGE	MID	266.1	69.502	872.5	723.3	723.3	576.7	576.7	710.9	710.9	2277.0	2883.4
DF	AVERAGE	BOT	19.4	93.308	289.5	411.7	536.0	530.7	530.7	1270.2	1270.2	2231.9	2626.4
DF	AVERAGE	TREE	473.3	71.140	1640.1	1432.5	1556.8	1242.1	1242.1	2023.6	2023.6	5171.5	6462.6

THERE IS ONLY ONE HOST. TOTALS FOR STAND ARE EQUAL TO THOSE PRINTED ABOVE.

Figure 3—Foliage summary tables (FOLSUM) are printed twice each year for each stand. The first one presents biomass in the spring (SPRING, not shown) before budworm feeding is simulated. The fall table (labled FALL) shows foliage statistics after defoliation has been simulated.

14

BIOMASS. When the table is labeled FALL, the amount of biomass listed under SUMMER BIOMASS is the amount left after defoliation. The ADJUSTED POTENTIAL is the amount available to be destroyed by the budworm.

% OF ADJUSTED	This quantity is the percentage of foliage eaten by budworm in the current year. When the table is labeled SPRG, for spring, this column contains zeros.
ADJUSTED POTENTIAL FOLIAGE	This quantity is the amount of foliage (grams) that is expected to be in the cell if it was not defoliated. To understand what the adjusted potential foliage is, let us first consider what the unadjusted potential foliage is. The unadjusted potential is the amount of biomass on a tree that has not been defoliated in recent years. If the tree had been defoliated, we assume that such defoliation reduces the tree's ability to grow new foliage the following year. Thus, if the tree were defoliated last year, the adjusted potential in the current year is lower than the unadjusted potential. The adjusted potential is the amount of foliage available to budworms to eat.

The other four groups are labeled 1-YR-OLD, 2-YR-OLD, REMAINING, and TOTAL. Each of these groups has only the SUMMER BIOMASS and ADJUSTED POTENTIAL categories, unlike the NEW FOLIAGE group, which also contains the % OF ADJUSTED category. The TOTAL group is an aggregation of all the foliage age classes.

The DETFOL output can be generated once for each 20-degree-day interval. This table lists the new foliage defoliation (DEFOL %) in column 3. The SHOOT EXPAN % (expansion) column indicates the expansion of shoots on the specific host and crown third. MEAN BW LIFE STAGE is the average instar of the budworm population. Budworm densities measured in number per square meter of foliage, number per 100 buds, and number per 100 grams of new foliage biomass follow. The number of budworm within the crown third is labeled TOTAL BW (#/CL). The proportions of the buds live, dead, and damaged are listed next. ACTUAL NEW FOLIAGE is the amount of new-foliage biomass within the crown third and POTENTIAL NEW FOLIAGE is the amount that would be within the crown third if there was no bud damage or defoliation. These biomass estimates take into account the current shoot expansion. The last two columns indicate the amount of foliage biomass that is in the crown third. The 1-YR-OLD FOLIAGE values assume full expansion; 2-YR & OLDER FOLIAGE is a sum across all foliage age classes.

FOLSUM NOFOLSUM	Print an annual summary of foliage dynamics (fig. 3). NOFOLSUM suppresses this output and is the default.
DETFOL NODETFOL	Print detailed host foliage data output; see the section "Population Dynamics" and fig. 4. NODETFOL suppresses this output and is the default. DETFOL is not available when using the Prognosis-Budworm Damage Model.
	field 1: The number of 20-degree-day intervals between detailed output of current model conditions; default = 1 (produces large volume of output).

HOST	DETFOL: BW TREE SIZE	CROWN THIRD	DEFOL (%)	SHOOT EXPAN (%)	MEAN BW LIFE STAGE	BW DENSITY (M2)	BW DENSITY (100B)	BW DENSITY (100G)	TOTAL BW (#/CL)	TOTAL NEW BUDS (#/CL)	PROPORTION OF TOTAL BUDS LIVE	DEAD	DAM.	ACTUAL NEW FOLIAGE (G/CL)	POTENT. NEW FOLIAGE (G/CL)	1-YR-OLD FOLIAGE (G/CL)	2-YR & OLDER FOLIAGE (G/CL)
DF	SMALL	TOP	1.1	2.1	2.0	56.2	4.2	8.4	2.	38.	0.99	0.01	0.00	3.	3.	6.	2.
DF	SMALL	MIDDLE	1.1	3.7	2.0	21.8	2.6	7.3	5.	208.	0.99	0.01	0.00	11.	11.	49.	41.
DF	SMALL	BOTTOM	1.1	3.5	2.0	16.1	1.8	8.4	10.	573.	0.99	0.01	0.00	18.	19.	106.	123.
DF	MEDIUM	TOP	1.1	2.1	2.0	30.0	4.5	8.9	21.	485.	0.99	0.01	0.00	33.	34.	167.	72.
DF	MEDIUM	MIDDLE	1.2	3.7	2.0	25.8	5.6	15.7	67.	1223.	0.99	0.01	0.00	65.	65.	359.	646.
DF	MEDIUM	BOTTOM	1.6	3.5	2.0	21.1	10.9	50.3	64.	593.	0.99	0.01	0.00	19.	19.	255.	893.
DF	LARGE	TOP	1.1	2.1	2.0	36.1	5.4	10.8	201.	3779.	0.99	0.01	0.00	261.	264.	1118.	745.
DF	LARGE	MIDDLE	1.2	3.7	2.0	23.9	5.2	14.5	486.	9527.	0.99	0.01	0.00	504.	510.	2794.	5030.
DF	LARGE	BOTTOM	1.5	3.5	2.0	15.3	7.9	36.6	363.	4621.	0.99	0.01	0.00	148.	150.	1987.	6955.

Figure 4—The 20-degree-day time step summary of foliage statistics with associated budworm information is generated using the DETFOL keyword.

Damage

The damage done to model trees by budworm is reported in a table generated by the DAMAGE keyword (fig. 5). This table is printed every 5 years, and at the end of the budworm model run. If the budworm model run is less than 5 years, the table is printed only at the end of the run. One row is printed for every model tree class. The first two columns of the table identify the host species and the size class. This output table is available from all budworm system programs.

DAMAGE: 1990; PERIOD LENGTH TO DATE: 5-YEARS

HOST	TREE SIZE	PROPORTION OF EXPECTED PERIODIC GROWTH DIAMETER	HEIGHT	MAXIMUM CUMULATIVE DEFOLIATION	NEW-FOLIAGE DEFOLIATION PERIOD AVERAGE TOP THIRD	WHOLE TREE	5-YR MAX AVERAGE TOP THIRD
DF	SMAL	0.331	0.112	405.8	0.937	0.884	0.937
DF	MED	0.202	0.522	373.5	0.640	0.851	0.693
DF	LARG	0.338	0.617	294.6	0.547	0.701	0.618

Figure 5—Damage output is requested using the DAMAGE keyword and is printed every 5 years or once at the end of the run when the run is of shorter duration.

The third and fourth columns identify the PROPORTION OF EXPECTED PERIODIC GROWTH. These columns contain the model's estimate of the reduction in diameter and height growth. Values near 1.0 indicate no impact on growth; values near 0.0 indicate 100 percent growth loss. Note that these growth loss figures apply only to trees that survive the budworm outbreak. Growth loss in height applies to trees that are not top damaged. If a tree is topkilled, the tree loses all of its height growth.

The MAXIMUM CUMULATIVE DEFOLIATION lists the largest cumulative defoliation measured for the tree class during the outbreak period. Cumulative defoliation is measured on a scale of 0 to 500 percent. Estimates of whole tree defoliation are computed by taking a ratio of the actual total biomass on the tree after defoliation and dividing it by the total adjusted potential biomass. Therefore, all foliage age classes are counted. The whole tree defoliation measurements for the past 5 years are added together. Each year, the program computes a new 5-year cumulative by deleting the oldest measurement and summing the five most recent estimates. The

largest of these cumulative measures are reported. The budworm-caused damage model uses this measurement to compute the probability of tree mortality.

NEW-FOLIAGE DEFOLIATION for the current period and the 5-YR MAX (maximum defoliation of new foliage for a 5-year period) is reported in the following three columns. The 5-YR MAX for the top third is used to compute the probability of top-kill and the amount of topkill.

DAMAGE   Print cumulative summary (fig. 5) of the results of budworm defo-
NODAMAGE   liation on hosts for each stand. NODAMAGE cancels this output.

The DAMAGE table is a summary that shows how damage affects budworm model trees. If the Prognosis-Budworm Damage Model or Prognosis-Budworm Dynamics Model is being used, the PERDAM keyword will generate a report (fig. 6) that displays how budworm damage affects individual Prognosis Model trees. This table is not available when using the Budworm Dynamics Model as it is not linked to the Prognosis Model.

```
PERDAM: 1995; BEAR_A86; M013            MORTALITY      DBH GROWTH    HT GROWTH      PROB  TOP
TREE              DBH  ORG HT  TREES   BASE    USED    BASE   USED   BASE   USED   OF TOP KILL
NO.    SP.       (IN)   (FT)   /ACRE  (/ACRE) (/ACRE)  (IN)   (IN)   (FT)   (FT)   KILL   (FT)
----   ---       -----  -----  -----  ------- ------- ------ ------ ------ ------  ------ ------
 185   DF1       17.60  81.81   .092    .003    .035   1.205   .494  5.133  2.128   .861     .0
   1   DF3       17.60  81.81   .222    .008    .012    .547   .255  2.553   .000   .885   19.8
 186   DF2       17.60  81.81   .055    .002    .004    .246   .053  1.396   .000   .897    8.0
 187   DF3       11.90  69.51   .202    .009    .022   1.309   .788  6.742   .000   .822   29.3
   2   DF1       11.90  69.51   .486    .021    .046    .601   .426  3.303  2.732   .806     .0
 188   DF2       11.90  69.51   .121    .005    .008    .272   .144  1.736   .000   .894   13.8
 189   DF3       15.20  77.45   .124    .004    .007   1.465   .786  6.643   .000   .892   12.8
   3   DF2       15.20  77.45   .298    .010    .016    .670   .510  3.247   .000   .877    7.6
 190   DF2       15.20  77.45   .074    .003    .003    .303   .131  1.708   .000   .787   10.4
 191   DF1        5.10  39.12  1.101    .114    .185    .834   .763  4.041   .000   .883    7.8
   9   DF2       10.70  66.00   .601    .024    .029    .704   .126  3.983   .000   .889   13.7
 202   DF3       10.70  66.00   .150    .006    .006    .320   .118  2.045   .000   .897   33.8
 203   DF3       10.00  76.00   .286    .014    .014   1.316   .300  7.195   .000   .863   34.6
  10   DF2       10.00  76.00   .688    .033    .072    .608   .437  3.525   .000   .830   11.5
 204   DF2       10.00  76.00   .172    .008    .012    .276   .123  1.839   .000   .829   13.1
 205   DF2       17.10  87.00   .098    .003    .007   1.414  1.209  5.929   .000   .899    7.8
  11   DF2       17.10  87.00   .235    .008    .021    .644   .355  2.917   .000   .894    9.5
 206   DF3       17.10  87.00   .059    .002    .004    .291   .074  1.560   .000   .728   46.1
```

Figure 6—When the Prognosis-Budworm Damage Model is used, the PERDAM keyword can be specified to display the effect budworm damage has on the growth and mortality rates of individual Prognosis Model sample trees.

PERDAM   Print periodic table that displays (fig. 6) the results of budworm
NOPERDAM   defoliation on Prognosis Model trees. NOPERDAM cancels the
                     output.

The first column of the periodic damage table contains the Prognosis Model tree number. This number can be used to merge output reported in this table with output created using the Prognosis Model's TREELIST option. The second column is the Prognosis Model tree species and value class identification. The tree's DBH and height before top damage are listed next. Column 5 lists the number of trees per acre that the Prognosis Model tree represents. MORTALITY estimated by the Prognosis Model (BASE) is followed by the value USED by the Prognosis-Budworm Dynamics Model. Likewise, DBH GROWTH and HT (height) GROWTH, are reported without (BASE) and with (USED) budworm damage. Finally, the model's estimate of the probability of topkill is reported. This number is compared to a random number and if the tree is topkilled, the model computes the amount of topkill, which is reported in the last column. Although the probability of topkill can be a number around 0.8, the amount of topkill for the tree can be zero feet.

Population Dynamics

There are four types of population dynamic summaries available by keyword control. These tables are available only using the Prognosis-Budworm Dynamics Model or the Budworm Dynamics Model. The FALSPR and POPSUM keywords produce one summary table for each stand and year of the projection. The DETPOP keyword produces a number of possible tabular combinations depending on the keyword field specification used. The FLYSUM keyword summary produces a summary table for all stands each year of the projection when net dispersal is selected (default), or one summary table for all stands and all years when you use the adult dispersal option.

The population summary table (POPSUM, fig. 7) produced at end of each year provides information by foliage cell (host, tree size, and crown third). First it gives progeny statistics for the previous generation. It provides egg-mass density per square meter and per hundred buds and converts this to eggs per hundred grams of foliage. Next it provides fourth-instar density using the same three measures. Fourth-instar densities are calculated at the Julian day when at least 50 percent of the model population has aged into the fourth instar. Percentage of shoot expansion is calculated at this Julian date as well. Next the number of viable adults that emerged from pupal cases is provided, followed by the proportion of that population that was female. A current-year-defoliation summary gives the percentage of new foliage consumed by budworm feeding in each foliage cell. This will not provide any measure of backfeeding (if it occurs); see the FOLSUM tables for this information. Finally, mortality factors that affected population dynamics between initial establishment at feeding sites and adult emergence are summarized as percentages of the total number of budworm that died in each foliage cell: during dispersal, due to bird predation, due to ant predation, due to fall-attacking parasite guild, due to spring-attacking parasite guild, due to variation in foliage quality, and, finally, due to direct suppression.

Any negative 1 that appears in the table indicates that the value was not calculated. In the case of proportion females, it indicates total population collapse in the cell while in other places (for example, foliage quality or insecticide spray), the associated options were not implemented.

The fall-spring population summary table (FALSPR, fig. 8) summarizes budworm population from the eggs laid in each foliage cell in the fall through the fall, winter, and spring mortality factors on a whole tree basis and finally provides the whole tree populations that will begin the search for new foliage (buds) in the spring.

This table also provides three tree statistics that are needed to interpret population statistics in measures commonly used in the field. The first column of numeric data is the stocking statistics associated with each budworm model tree. Total foliage biomass and square meters of foliage provide you with means to interpret other data with respect to these bases. The initial number of eggs per crown third is shown including those that are nonviable and parasitized. The total number of egg

POPSUM: YEAR=1986	BW TREE SIZE	CROWN THIRD	EGG MASS DENSITY (M2)	EGG MASS DENSITY (100B)	EGG DENSITY (100G)	L4 DENSITY (M2)	L4 DENSITY (100B)	L4 DENSITY (100G)	EXPAN AT L4	NO. OF ADULTS	PROP. FEMALE	% DEFOL	FROM L2(SPRING)-ADULT EMERGENCE: PROP. OF MORTALITY DUE TO:						
HOST													DISP	BIRDS	ANTS	PAR1	PAR2	FQUAL	SPRAY
DF	SMALL	TOP	8.7	1.6	90.8	260.5	45.1	90.6	98.	11.	0.499	68.	0.28	0.02	0.20	0.30	0.19	-1.00	-1.00
DF	SMALL	MIDDLE	6.0	1.1	58.8	123.5	22.9	64.5	97.	28.	0.500	47.	0.35	0.02	0.19	0.27	0.16	-1.00	-1.00
DF	SMALL	BOTTOM	3.0	0.5	31.3	96.7	15.2	70.0	99.	50.	0.500	51.	0.45	0.02	0.16	0.23	0.14	-1.00	-1.00
DF	MEDIUM	TOP	7.4	1.9	78.2	165.6	41.2	82.8	98.	124.	0.500	60.	0.11	0.02	0.14	0.45	0.27	-1.00	-1.00
DF	MEDIUM	MIDDLE	5.0	1.4	49.0	179.8	49.7	139.9	97.	335.	0.500	99.	0.10	0.02	0.26	0.40	0.23	-1.00	-1.00
DF	MEDIUM	BOTTOM	2.8	1.5	28.7	175.3	95.2	438.3	99.	48.	0.046	100.	0.44	0.01	0.16	0.36	0.04	-1.00	-1.00
DF	LARGE	TOP	20.9	5.4	218.9	112.9	28.4	57.0	98.	661.	0.500	41.	0.22	0.06	0.00	0.45	0.27	-1.00	-1.00
DF	LARGE	MIDDLE	13.3	3.8	129.9	105.0	29.5	83.0	97.	1744.	0.500	59.	0.20	0.06	0.00	0.46	0.27	-1.00	-1.00
DF	LARGE	BOTTOM	9.7	5.4	101.3	82.5	45.7	210.6	99.	610.	0.048	100.	0.29	0.04	0.11	0.43	0.12	-1.00	-1.00

Figure 7—Annual population summary for a stand is controlled by the POPSUM keyword.

```
FALSPR: 1985-1986
                                TOTAL
                             ADJUSTED     TOTAL
                 BW           FOLIAGE    ADJUSTED   INITIAL NO.                 PROP. KILLED    PROP. KILLED
                TREE   CROWN  BIOMASS    FOLIAGE   OF EGGS PER   TOTAL NO. OF   DURING FALL      DURING     NO. OF L2S THAT
                                                                              DISPERSAL      BASE SPRING   SEARCH FOR BUDS
         HOST  SIZE   THIRD   (GRAMS)     (M2)    CROWN THIRD   PER MODEL TREE OVER-WINTER     DISPERSAL    PER MODEL TREE
         ----  ----   -----   -------    -------  -----------   ------------- ------------    ------------  ---------------

          DF   SMALL    TOP     27.06      0.07      22.6
          DF   SMALL  MIDDLE   162.33      0.40      88.0
          DF   SMALL  BOTTOM   351.72      0.92     101.5
          DF   SMALL   TREE    541.11      1.38                    212.1          0.55           0.14            66.8

          DF  MEDIUM    TOP    478.41      1.25     344.6
          DF  MEDIUM  MIDDLE  1435.22      3.51     648.0
          DF  MEDIUM  BOTTOM  1275.75      3.32     337.4
          DF  MEDIUM   TREE   3189.37      8.08                   1330.0          0.55           0.13           418.9

          DF   LARGE    TOP   3725.98      9.75    7510.8
          DF   LARGE  MIDDLE 11177.96     27.33   13373.9
          DF   LARGE  BOTTOM  9935.96     25.87    9269.5
          DF   LARGE   TREE  24839.90     62.96                  30154.2          0.55           0.14          9498.6
```

Figure 8—The fall-spring population summary for a stand is controlled by the FALSPR keyword.

eclosions (or hatched first-instar larvae) on each model tree is followed by the proportions killed during the fall-winter and initial spring dispersal as second instars searching for feeding sites. These values are provided on a per-model-tree basis because significant off-foliage movement takes place between egg hatch and establishment at feeding sites.

POPSUM Print an annual summary (fig. 7) of population dynamics for each
NOPOPSUM stand NOPOPSUM suppresses this output. This output is not available when using the Prognosis-Budworm Damage Model.

FALSPR Print the fall-spring population summary table (fig. 8) for each
NOFALSPR stand each year. NOFALSPR suppresses this output. This output is not available when using the Prognosis-Budworm Damage Model.

The detailed population summaries come in three outputs (fig. 9). The first two single-line statements are printed once per year per stand: the first gives the Julian date for extreme cold temperature (if the event occurs) and the other gives the date when all larvae have emerged from hibernation (not illustrated). The detailed population table may be printed more than 40 times for each stand each year. To reduce this large volume of output, increase the number of intervals between printings.

```
YEAR 1986; STAND ID: BEAR01 ; MANAGEMENT ID: NONE; OUTPUT FOR INTERVAL   3; JULIAN DAY: 154; DEGREE-DAYS TO DATE:  141.

DETPOP:                              MEAN                                     PROPORTION OF TOTAL BUDWORMS BY LIFE STAGE
          BW                       SHOOT  BW    BW      BW      BW    TOTAL   --------------------------------------------------
         TREE  CROWN  DEFOL  EXPAN LIFE DENSITY DENSITY DENSITY  BW   PROP.   SECOND  THIRD  FOURTH  FIFTH  SIXTH
   HOST  SIZE  THIRD   (%)    (%)  STAGE  (M2)  (100B)  (100G) (#/CL) FEMALE  INSTAR INSTAR INSTAR INSTAR INSTAR  PUPAE  ADULTS
   ----  ----  -----  -----  ----- ----- ------ ------- ------- ------ ------ ------ ------ ------ ------ ------ ------ ------

    DF   SMALL   TOP    1.3   3.8   2.0   143.0   10.9    21.8    4.   0.50    1.00   0.00   0.00   0.00   0.00   0.00   0.00
    DF   SMALL MIDDLE   1.3   6.2   2.0    55.8    6.8    19.0   14.   0.50    1.00   0.00   0.00   0.00   0.00   0.00   0.00
    DF   SMALL BOTTOM   1.3   6.2   2.0    41.4    4.8    21.9   27.   0.50    1.00   0.00   0.00   0.00   0.00   0.00   0.00

    DF  MEDIUM   TOP    1.4   3.8   2.0    77.2   11.6    23.3   56.   0.50    1.00   0.00   0.00   0.00   0.00   0.00   0.00
    DF  MEDIUM MIDDLE   1.6   6.2   2.0    67.0   14.6    41.0  177.   0.50    1.00   0.00   0.00   0.00   0.00   0.00   0.00
    DF  MEDIUM BOTTOM   2.8   6.2   2.0    55.2   28.6   131.9  168.   0.50    1.00   0.00   0.00   0.00   0.00   0.00   0.00

    DF   LARGE   TOP    1.4   3.8   2.0    89.9   13.5    27.2  506.   0.50    1.00   0.00   0.00   0.00   0.00   0.00   0.00
    DF   LARGE MIDDLE   1.5   6.2   2.0    60.0   13.1    36.8 1232.   0.50    1.00   0.00   0.00   0.00   0.00   0.00   0.00
    DF   LARGE BOTTOM   2.3   6.2   2.0    38.9   20.2    92.9  923.   0.50    1.00   0.00   0.00   0.00   0.00   0.00   0.00
```

Figure 9—Detailed population summary printed at specified 20-degree-day intervals is controlled by the DETPOP keyword.

The third detailed population summary begins with a banner giving the year, stand and management identifications, the 20-degree-day interval counter value, the Julian date, and the degree-days accumulated to date. For each host foliage cell, the cumulative defoliation, mean development (the model carries an array of population ages), current budworm density per square meter, per 100 buds, and per 100 grams of foliage, total population in the cell, proportion of that population that is female, and distribution of life stages are displayed.

DETPOP Print detailed budworm population data output for each stand
NODETPOP each year. NODETPOP turns off this output and is the default. This output is not available when using the Prognosis-Budworm Damage Model.

   field 1: The number of 20-degree-day intervals between detailed output of current model conditions; default = 1.

There are two adult dispersal options. When two or more stands are present, adult dispersal between stands can be simulated and the dispersal statistics printed (fig. 10). This table contains stand-wide statistics by year for each stand simulated. Stand and management identifications are used to identify the stands. The area of each stand is presented in hectares. The total amount of foliage (square meters per hectare) provides the basis for conversions. The initial number of potential eggs is the total number carried by all female adults before any egg masses are laid or adults fly and in-flight mortality is applied. Preflight mortality rate and eggs laid before adult females leave the stand are provided next. Some females will return to their stand of origin after flight. Eggs killed during flight is the number of eggs that die during flight of the female. These dead eggs are associated with the females' original stand. The total number of eggs laid has been calculated and is provided in units of eggs per stand. The stand biomass (square meters per hectare and stand area) is used to calculate an average egg-mass density for the stand.

```
              WESTERN SPRUCE BUDWORM MODEL        VERSION  3.00      08-20-1990  10:34:24

FLYSUM: ADULT DISPERSAL SUMMARY
                                                                EGGS     EGGS     EGGS
                                                                KILLED   LAID     KILLED
                            STAND    HOST    INITIAL NO.  INITIAL BEFORE  BEFORE   DURING   TOTAL NO.    FINAL
              STAND  MGMT   AREA     FOLIAGE POTENTIAL    EGG MASS FLIGHT FLIGHT   FLIGHT   EGGS LAID    EGG MASS
       YEAR   IDENT  IDENT  (HA)     (M2/HA) EGGS         DENSITY  (%)    (%)      (%)      POST DISPERSAL DENSITY
                                             (EGGS/HA)    (EM/M2)                           (EGGS/HA)    (EM/M2)
       ----   ------ ------ -------- ------- ------------ -------- ------ -------  -------  ------------ --------
       1986
              BEAR01 NONE   18.0     15728.2 0.6770E+08   85.0     20.0   26.0     13.5     0.4447E+08   55.9
              BEAR02 NONE   32.0     9629.8  0.4056E+08   81.8     20.0   26.1     13.5     0.2700E+08   54.4
              BEAR03 NONE   18.0     12158.6 0.5018E+08   81.4     20.0   26.0     13.5     0.3381E+08   54.9
       1987
              BEAR01 NONE   18.0     4470.0  0.1390E+07   1.7      20.0   63.0     7.9      0.1445E+07   1.8
              BEAR02 NONE   32.0     3131.1  0.3309E+07   6.7      20.0   31.1     22.7     0.1429E+07   2.9
              BEAR03 NONE   18.0     3763.3  0.8550E+06   1.4      20.0   59.4     9.6      0.9876E+06   1.6
       1988
              BEAR01 NONE   18.0     4433.1  0.3583E+07   4.5      20.0   26.3     25.1     0.1892E+07   2.4
              BEAR02 NONE   32.0     3075.1  0.2727E+07   5.5      20.0   26.3     25.1     0.1376E+07   2.8
              BEAR03 NONE   18.0     3775.7  0.1812E+07   2.9      20.0   26.4     25.0     0.1288E+07   2.1
       1989
              BEAR01 NONE   18.0     3589.3  0.6869E+07   8.6      20.0   25.5     27.5     0.3095E+07   3.9
              BEAR02 NONE   32.0     2513.9  0.3144E+07   6.3      20.0   26.2     27.1     0.1765E+07   3.6
              BEAR03 NONE   18.0     3134.7  0.3155E+07   5.1      20.0   26.3     27.1     0.2002E+07   3.2
       1990
              BEAR01 NONE   18.0     3996.1  0.1953E+08   24.5     20.0   26.0     26.1     0.8592E+07   10.8
              BEAR02 NONE   32.0     2654.0  0.6035E+07   12.2     20.0   26.1     26.0     0.3901E+07   7.9
              BEAR03 NONE   18.0     3850.1  0.9239E+07   15.0     20.0   26.1     26.0     0.5789E+07   9.4
```

Figure 10—The adult dispersal summary is printed when the FLYSUM keyword is specified and the dispersal between stands is simulated.

Adult dispersal summaries under the net dispersal option (fig. 11) are printed once each year. The stand identification number, management identification, and total host foliage in square meters per hectare are followed by mean stand-egg-mass density from the previous generation. The potential number of eggs, given in eggs per hectare, is summed for all adult females from all hosts in the stand. Next is the total eggs lost due to the net dispersal assumption (default = 20 percent), followed by the difference between the previous two columns, the total number of new eggs, both given in eggs per hectare. The final entry is the average density of egg masses per square meter over all host foliage in the stand.

FLYSUM Print yearly summary of budworm dispersal dynamics (fig. 11).
NOFLYSUM NOFLYSUM cancels yearly summary of budworm dispersal dynamics. This output is not available when using the Prognosis-Budworm Damage Model.

```
FLYSUM: NET DISPERSAL SUMMARY

                        1986     ----------------1987-------------------
                HOST    INITIAL  POTENTIAL LOST EGGS TOTAL NO. FINAL EGG
    STAND  MGMT FOLIAGE NO. EGGS NO. EGGS  DISP/MORT NEW EGGS  DENSITY
    IDENT  IDENT (M2/HA) (EGGS/HA) (EGGS/HA) (EGGS/HA) (EGGS/HA) (EM/M2)
    -------- ------ ------- --------- --------- --------- --------- ---------

    BEAR01 NONE    4626. .5416E+08 .1385E+07 .2770E+06 .1108E+07    6.0
    BEAR02 NONE    3052. .3245E+08 .2247E+07 .4493E+06 .1797E+07   14.7
    BEAR03 NONE    3601. .4014E+08 .8877E+06 .1775E+06 .7101E+06    4.9
```

Figure 11—The adult dispersal summary is printed when the FLYSUM keyword is specified and the net dispersal option is used.

Special Output

All of the output described so far has been designed to be printed on a standard computer line printer. Sometimes it is worthwhile to have output written in a machine-readable format for additional analysis or for making graphic output. The STATDATA option was created for this purpose. The output record formats of this option are described in appendix B, page 56.

When the Budworm Dynamics Model is used, it is possible to generate a file of defoliation estimates that has the same data elements and record format as the DEFOL keywords. You can therefore use the Budworm Dynamics Model to create a file of DEFOL keywords and then, in a later run, use these DEFOL keywords as input to the Prognosis-Budworm Dynamics Model.

Programmers and some users need to see additional output and program traces. The DEBUG option provides for this need. The DEBUG option changes all of the output in another important way. When the Prognosis-Budworm Model is run without DEBUG, all of the Budworm Dynamics Model output is stored on a temporary file and printed after the Prognosis Model output is printed. The DEBUG option causes the Budworm Model output to be printed as it is created; the temporary file is not used.

Finally, you can use the PREDMORT keyword to generate some debug-type output regarding predator-caused budworm mortality.

STATDATA Creates machine-readable output files of yearly model statistics.

field 1: Data set reference number for foliage biomass output; if blank, these data are not written.

field 2: Data set reference number for population output; if blank, these data are not written. This output is not available when using the Prognosis-Budworm Damage Model.

21

<table>
<tr><td></td><td>field 3:</td><td>Data set reference number for annual damage output; if blank, these data are not written.</td></tr>
<tr><td></td><td>field 4:</td><td>Data set reference number for periodic damage output; if blank, these data are not written. This output is available only when using a budworm program that includes the Prognosis Model.</td></tr>
<tr><td></td><td>field 5:</td><td>Data set reference number for dispersal model output; if blank, these data are not written. This output is not available when using the Prognosis-Budworm Damage Model.</td></tr>
<tr><td>**WRTDEFOL**</td><td colspan="2">Generate a file of DEFOL keywords.</td></tr>
<tr><td></td><td>field 1:</td><td>The data set reference number for the output. If a zero is entered no DEFOL keywords are written.</td></tr>
<tr><td>**DEBUG** **NODEBUG**</td><td colspan="2">Activate debug output for the budworm model. NODEBUG deactivates debug output.</td></tr>
<tr><td></td><td>field 1:</td><td>Enter the debug level. Programmers must consult the source code to determine a useful level.</td></tr>
<tr><td></td><td>field 2:</td><td>Enter the data set reference number of budworm model output. Useful to ensure output from all parts of a single computer program is output in one sequential file.</td></tr>
<tr><td>**PREDMORT**</td><td colspan="2">Activate predator output (no example is illustrated).</td></tr>
</table>

Example 4: Requesting Output (not illustrated)—To expand example 3 to include a request that foliage and population dynamics summaries be printed, simply enter the FOLSUM and POPSUM keywords between lines 7 and 8 in the keyword file illustrated in example 3, page 11.

USING THE BUDWORM DYNAMICS MODEL

In this section, the use of the "stand alone" Budworm Dynamics Model is explained. Most of the keywords used by the Budworm Dynamics Model can also be used by the Prognosis-Budworm Dynamics Model. Therefore, this part of the user's guide is applicable even if you intend to use the Prognosis-Budworm Dynamics Model. How to generate a file of the foliage and stand statistics useful for running the Budworm Dynamics Model has already been covered.

The differences between the Budworm Dynamics Model and the Prognosis-Budworm Dynamics Model are important to remember. Only one stand at a time can be represented by the Prognosis-Budworm Dynamics Model. A single stand is entered and projected from the inventory date for a specified period. You may enter a second or subsequent stand in the same model run, but each is simulated independently. In the Budworm Dynamics Model, several stands are entered before the simulation begins. Biological processes in all stands are simulated through time in parallel so that budworm dispersal between stands can be explicitly simulated.

There are two levels of Budworm Dynamics Model keywords. The first level, called all-stand keywords, is those that apply to all stands. The keywords that control adult dispersal logic are examples.

The second level, called stand-specific keywords, includes keywords that apply to only specific stands. An example is the keyword that is used to enter estimates of budworm eggs. All of the output options, such as the POPSUM, FOLSUM, and DAMAGE tables previously described, are also stand-specific options. Therefore, you can control which output tables are generated for individual stands.

Because Prognosis-Budworm Dynamics Model processes only one stand at a time, the distinction between all-stand and stand-specific keywords is moot.

Simple Budworm Dynamics Model Runs

To use the Budworm Dynamics Model, you must first generate a file that contains the foliage and stand statistics needed by the Budworm Dynamics Model. This is done using the WRITEFOL keyword described under the Prognosis-Budworm Dynamics Model and illustrated in example 1. Appendix A contains a more complete example.

Keywords for Simple Runs—To enter a single stand into the Budworm Dynamics Model, use the ADDSTAND keyword. It will tell the Budworm Dynamics Model to read the foliage and stand statistics for the first stand stored in the file using WRITEFOL keywords. It also tells the Budworm Dynamics Model that the keywords entered between ADDSTAND and END are only applicable to the stand being read in, that is, they are stand-specific keywords.

ADDSTAND   Add one stand for processing by the Budworm Dynamics Model.

> field 1:   Data set reference number (no default).

END   Signal the end of one stand's input.

After the END keyword has been entered, you may enter keywords applicable to all stands or another ADDSTAND—END series to enter a second or subsequent stand.

A PROJECT keyword is entered to signal that the simulation should start and run until the year coded in field 1. After the model finishes, it will read another keyword. If you enter a STOP keyword, the model will stop; any other keywords will be processed normally. You can enter several PROJECT keywords, each with a succeeding date. Therefore, you can simulate a population for a few time steps and then change some model options before continuing the simulation. The maximum length of the simulation cannot exceed 15 years.

The STARTYR keyword is used to specify the first year of the projection. Because the Budworm Dynamics Model does not contain tree growth models, its time horizon is limited to the time you are willing to assume that tree growth will not seriously affect the results. The Budworm Dynamics Model does simulate foliage growth and dynamics; however, the potential foliage remains constant.

For many uses, this assumption causes no problems. In most stands, you can assume that the potential biomass per acre will change so slowly as to remain constant over a short period, say up to 5 or 10 years. That is why the Budworm Dynamics Model does not have a long time horizon.

PROJECT, STARTYR, and STOP are all-stand keywords.

PROJECT   Signal the Budworm Dynamics Model to run the projection. If no stands have been added (see ADDSTAND above), the model stops.

> field 1:   The year you want the simulation to stop (default is 1 year after the current STARTYR).

STARTYR   Enter the first year of the projection period.

> field 1:   The starting date of the projection (default is the year the foliage was generated using the WRITEFOL keyword for the first stand encountered).

STOP   Stop the model.

Example 5: Simple Run—Let us assume that you have created a foliage and stand statistics file using the WRITEFOL option in the Prognosis-Budworm Dynamics Model. Your run was much like the run illustrated in example 1. Two stands were processed and the foliage and stand data for both reside in a file referenced by data set reference number 20. The run will be made with default options except that foliage and population summary tables are requested.

Reference line	Keyword	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7
1	ADDSTAND	9.						
2	FOLSUM							
3	POPSUM							
4	END							
5	ADDSTAND	9.						
6	FOLSUM							
7	POPSUM							
8	END							
9	PROJECT							
10	STOP							

Line 1: ADDSTAND signals the Budworm Dynamics Model to read the foliage and stand statistics for the first stand.

Lines 2 and 3: FOLSUM and POPSUM request the foliage and population summary output.

Line 4: Signals the end of the options applicable to the first stand.

Lines 5 through 8: Like lines 1 through 4, except that they apply to the second stand.

Lines 9 and 10: Project these stands 1 year and then stop.

Using All-stand and Stand-specific Keywords—If you want to input a large number of stands, and want the same output options, or other stand-specific options, for all of the stands, you might specify them over and over again for each stand. The Budworm Dynamics Model provides an alternative method by allowing stand-specific keywords outside of ADDSTAND—END groups. If a stand-specific keyword is encountered outside of an ADDSTAND—END group, it affects all subsequent ADDSTAND—END groups. It has no effect on prior ADDSTAND—END groups. If it conflicts with a keyword specified within an ADDSTAND—END group, the keyword inside the group is used.

Therefore, stand-specific keywords can be specified anywhere in the runstream. All-stand keywords can only be specified outside of ADDSTAND—END groups. A stand-specific keyword placed after the last ADDSTAND—END in the runstream has no effect. The all-stand keywords affect all stands, regardless of their position in the runstream.

You may assume keywords are stand-specific unless they are labeled as all-stand keywords in their descriptions.

Example 6: Using Stand-specific Keywords (not illustrated)—In example 5, The FOLSUM and POPSUM keywords were each specified twice, once for each stand. Because they are stand-specific keywords, they could have been specified once before the first ADDSTAND keyword. This sequence would make them apply to all of the stands in the run.

Multiple Budworm Dynamics Model Runs

The Budworm Dynamics Model can be used to run more than one complete run each time the program is started. To use this facility, you must enter the RESET keyword after the final PROJECT keyword for the first complete run and before the STOP keyword. After RESET, you can enter ADDSTAND and other options just like you did for the first run. RESET causes the Budworm Model to recall all of the default conditions (except the default Weather Model options). If RESET is specified within an ADDSTAND—END group, it cancels all keywords specified *within* that ADDSTAND—END group, and does not affect the projection in any other way.

RESET   Recall the default values for all options. If used within an ADDSTAND—END group, this keyword applies only to one stand. Otherwise, this keyword applies to the entire Budworm Dynamics Model.

Setting Initial Conditions

Initial Egg Densities and Distribution—There are two methods to set initial egg-mass densities in each stand:

- Use the AVEGGD keyword to specify the densities in the midcrowns of medium-size trees. Relative egg-mass densities are used by the model to set the densities in other foliage cells (see equation 3, p. 16, Sheehan and others 1989).

- Use the TOTEGG keyword to specify the total number of eggs per hectare to be distributed to host foliage cells. Additional keywords are used to control how these eggs are distributed.

When the TOTEGG option is used, the total eggs per hectare are distributed among host model trees in proportion to the number of trees per hectare and the distribution of foliage in each foliage cell. These factors are further weighted by relative egg mass densities per square meter of foliage (see equations 4 and 5, p. 18, Sheehan and others 1989). The REGGDEN keyword may be used to modify these weights. Relative egg mass densities are not stand specific; these weights are used similarly in all stands to distribute eggs. The total egg complement for a stand is assigned to foliage cells to achieve the relative egg-mass densities shown in table 5. For example, for every egg mass per square meter of foliage in midcrown of medium-sized trees, there will be 4.17 egg masses per square meter in the tops of large trees.

Regardless of the method used to set initial egg-mass densities, the relative egg-mass densities per square meter are used to distribute the eggs to foliage cells of host model trees. These relative densities are also used for distributing eggs in all subsequent years.

Any data on egg-mass density from 45-cm tip samples from medium-sized (7- to 14-m) trees should be multiplied by 0.82 (Campbell and others 1984) to convert to whole branch densities.

When using the Prognosis-Budworm Dynamics Model, the start of a simulated budworm outbreak is scheduled and the year must be entered (field 1) on the AVEGGD or TOTEGG keyword. The value(s) provided will be used to initialize the model at the start of the Prognosis cycle associated with the year provided; for example, if a 10-year cycle starts in year 1990 and the year given was 1995, then the values will be used to start the Prognosis Budworm Dynamics Model in 1990. Careful attention must be given to cycle lengths and inventory years to produce properly synchronized budworm outbreaks. When using the Prognosis-Budworm Dynamics Model, several outbreaks can be scheduled. See the CALLBW keyword for further details.

If neither the AVEGGD nor the TOTEGG keyword is used, the model default is to initialize each host in each stand by using the relative egg-mass densities and setting the density of midcrowns of medium-sized trees to 5.0 egg masses per square meter.

AVEGGD	Specify the average egg density (egg masses per square meter) on the midcrowns of the medium-sized budworm model trees at the beginning of the simulation. Default = 5.0 egg masses per square meter for all hosts.

field 1: Year this option is to be scheduled in the Prognosis-Budworm Dynamics Model (default = 1.0). This field is ignored by the Budworm Dynamics Model.

field 2: Average number of egg masses per square meter on midcrowns of medium-sized white fir trees.

field 3: Average number of egg masses per square meter on midcrowns of medium-sized Douglas-fir trees.

field 4: Average number of egg masses per square meter on midcrowns of medium-sized grand fir trees.

field 5: Average number of egg masses per square meter on midcrowns of medium-sized subalpine fir trees.

field 6: Average number of egg masses per square meter on midcrowns of medium-sized Engelmann spruce trees.

TOTEGG Specify the total number of western spruce budworm eggs per hectare for a stand at the beginning of a simulation in units of 1,000. Default = 50.0 thousand eggs per hectare.

field 1: Year this option is to be scheduled in the Prognosis-Budworm Dynamics Model (default year = 1.0). This field is ignored by the Budworm Dynamics Model.

field 2: Thousands of budworms per hectare for the stand.

REGGDEN Relative egg mass densities to be used to determine egg densities per foliage cell. All values are based on differences between egg mass densities in the crowns of medium trees. Default values can be found in table 5. This is an all-stand keyword.

field 1: Numeric tree species code; required, table 3.

field 2: Relative egg mass density of the upper crowns of small trees.

field 3: Relative egg mass density of the midcrowns of small trees.

field 4: Relative egg mass density of the lower crowns of small trees.

field 5: Relative egg mass density in the upper crowns of medium trees.

field 6: Relative egg mass density in the midcrowns of medium trees.

field 7: Relative egg mass density in the lower crowns of medium trees.

Supplemental data record:

cols 1-10: Relative egg mass density in the upper crowns of large trees.

cols 11-20: Relative egg mass densities in the midcrowns of large trees.

cols 21-30: Relative egg mass densities in the lower crowns of large trees.

Table 5—Default values of REGGDEN, by crown third (foliage cell) and host tree species
(from table 10B, p. 19, Sheehan and others 1989)

Model tree	Crown third	White fir	Douglas-fir	Grand fir	Subalpine fir	Engelmann spruce
Small	upper	1.73	1.73	1.73	1.73	1.73
	mid	1.20	1.20	1.20	1.20	1.20
	lower	.60	.60	.60	.60	.60
Medium	upper	1.49	1.49	1.49	1.49	1.49
	mid	1.00	1.00	1.00	1.00	1.00
	lower	.55	.55	.55	.55	.55
Large	upper	4.17	4.17	4.17	4.17	4.17
	mid	2.65	2.65	2.65	2.65	2.65
	lower	1.94	1.94	1.94	1.94	1.94

Stand Locations and Size—The STNDLOCS keyword is used to enter the spatial data required by the Budworm Dynamics Model's adult dispersal logic. This keyword is used to signal that the stand location file be read in much the same way the ADDSTAND keyword is used to signal the foliage file be read.

The information contained in this file must be generated from some source such as a geographic information system. If you do not have an automated method to generate this file, code the necessary data by hand.

STNDLOCS   Read in stand locations and sizes. This is an all-stand keyword.

field 1:   Dataset reference number for stand location records; default is the same file used to read keywords.

field 2:   A multiplier used to scale area data to hectares; default is 1.0.

field 3:   A multiplier used to scale location data to kilometers; default is 1.0.

Supplemental data records:

cols 1-8:   Stand identification code used to identify the stand in the Prognosis Model via the STDIDENT keyword.

cols 11-20:   Stand area (see field 2).

cols 21-30:   X-coordinate for stand centroid (see field 3).

cols 31-40:   Y-coordinate for stand centroid (see field 3).

The stand location records may be read in the same file as the keywords. If this is done, a special end-of-data marker must be present to signal that all-stand location records have been read. This is done by entering a record with –999 coded between columns 1-8. If the file is read from an external file, the actual end-of-file marker may take the place of the –999 record.

The stand location file must contain a record for every stand for which you have an ADDSTAND. The stand identification codes are used to match the stand locations with the foliage and stand data; therefore, care must be taken to use the same coding scheme.

You may enter stand location records for stands other than those you are including in the projection. These extraneous records will be ignored.

Simulating Management Actions

Budworm population suppression and the effects of manipulating stand structure can be simulated. Suppression, using the spray options, is covered below followed by manipulating stand structure. Other management activities may be possible by using the other model options in some creative way. Be creative, and be careful!

Direct Population Suppression—Mortality due to spraying insecticide is controlled using four different keywords. The keywords can be used in various combinations to simulate the decision making activities leading to an application date besides controlling the spray itself.

The SPRAY keyword is used to signal that spray is to be applied if some criteria are met and to start checking the criteria in the year entered on the SPRAY keyword.

Once the spray logic is turned on, you can control the frequency spray is applied. The number of years between applications is entered on the SPRAY keyword following the year the spray logic is activated.

The Budworm Dynamics Model computes several statistics that entomologists traditionally use when deciding if and when to spray. The SPRAYREQ keyword is used to enter four criteria that must be met before spray will be applied: (1) The new foliage defoliation in the previous year must have exceeded a level that you enter. (2) The spring second-instar density must exceed a level that you enter. (3) The percentage of shoot elongation must be greater than a percentage that you enter. (4) The average life stage of the larvae must be greater than a stage that you enter. The spray is applied on the Julian day that these criteria are met.

You define the amount of mortality caused by the spray using the EFFICACY keyword. The efficacy can be controlled separately for budworm males and females and for budworms of each larval stage from second instar to sixth.

The final keyword is NOSPRAY. Enter the year you want spraying to end on this keyword.

When you use these keywords within the Prognosis-Budworm Dynamics Model, they work slightly differently than they do in the Budworm Dynamics Model. In the Prognosis-Budworm Dynamics Model, the SPRAY keyword is treated like an activity, just like the DEFOL keywords are treated. Therefore, you can specify more than one SPRAY, NOSPRAY, SPRAYREQ, or EFFICACY keyword, each with a different date. The parameters will take effect the year the keyword is scheduled by the model. In the Budworm Dynamics Model, you can enter only one SPRAY, NOSPRAY, SPRAYREQ, or EFFICACY keyword.

SPRAY Turn on the possibility of insecticide application.

field 1: Year when spraying is to be allowed if conditions described by SPRAYREQ are met. The default is the first year of the simulation.

field 2: Waiting time in years between applications; default is 0 years.

NOSPRAY Turn off the possibility of insecticide application.

field 1: Year spraying is turned off. The default is the first year of the simulation.

SPRAYREQ Specify the criteria that must be exceeded before insecticide is applied. These criteria are checked for the first stand entered into the Budworm Dynamics Model unless a different stand has been specified (see the SPRYINDC keyword in the following section). The Julian day all criteria are met in that stand is the spray day for all of the stands.

field 1: The year this keyword will take effect; default = 1. This field is ignored by the Budworm Dynamics Model.

field 2: The percentage of defoliation of the previous year's new foliage defoliation that must be exceeded before spray is applied; default is 50 percent.

28

field 3:   Spring second-instar density per 100 shoots that must be exceeded before spray is applied; default is 10 per 100 shoots.

field 4:   Percentage of shoot elongation that must be exceeded before spray is applied; default is 10 percent.

field 5:   Average life stage of the budworm population that must be exceeded before spray is applied; default is 4.0, which means that the average instar is fourth instar.

EFFICACY   Specify mortality rates to be simulated when an insecticide is applied by life stage and sex. Default values for fields 3-7 are 0.91 for all instars and both sexes. Specify separate EFFICACY keywords for each sex.

field 1:   The year this keyword will take effect; default = 1. This field is ignored by the Budworm Dynamics Model.

field 2:   Budworm sex class; (1 = male, 2 = female); default = 2.

field 3:   Proportion of second-instar budworms (of sex identified in field 2) that are killed by insecticide applications.

field 4:   Proportion of third-instar budworms (of sex identified in field 2) that are killed by insecticide applications.

field 5:   Proportion of fourth-instar budworms (of sex identified in field 2) that are killed by insecticide applications.

field 6:   Proportion of fifth-instar budworms (of sex identified in field 2) that are killed by insecticide applications.

field 7:   Proportion of sixth-instar budworms (of sex identified in field 2) that are killed by insecticide applications.

Multistand Spraying—Spraying stands on an individual basis is not usually done in practice. Instead, stands are sprayed in blocks. One stand in the block is monitored, and if conditions in that stand require spraying, the whole block is sprayed. The monitored stand is called the INDICATOR stand. It is identified using the SPRYINDC keyword. The group of stands to be sprayed is set apart from the rest of the stands in the run by using the SPRYUNIT keyword.

SPRYUNIT   All of the stands that follow this keyword will be sprayed as a block. This is an all-stand keyword. Only one block can be designated during a run.

ENDSPRYU   Stop adding stands to the spray unit.

SPRYINDC   Identify the indicator stand by placing this keyword inside the ADDSTAND—END group that should serve as the indicator stand. Alternatively, the stand number can be specified in the first field of this keyword. The stand number is the sequence number for stands entered into the model. For example, stand number 1 refers to the first stand entered, stand number 2 refers to the second, and so on. Do not enter the stand identification code.

field 1:   Stand number corresponding to the spray indicator stand. If left blank, the stand number for the current stand will be used.

SPRYUNIT must be specified before the first ADDSTAND—END group of interest. If SPRYUNIT is specified after the last ADDSTAND—END group in the run-stream, it has no effect. If the SPRYUNIT keyword is encountered, all subsequent ADDSTAND—END groups will be sprayed as a single group until the ENDSPRYU

29

keyword is reached (if ever). SPRYUNIT cannot be specified within an ADDSTAND—END group.

The SPRYINDC keyword must be specified within an ADDSTAND—END group. If the SPRYINDC keyword is specified in a stand not covered by the SPRYUNIT keyword, or the SPRYINDC keyword is not specified, the first stand following the SPRYUNIT keyword is assumed to be the indicator stand.

The final step in triggering a multistand spray is to use the SPRAY keyword, and/or the NOSPRAY and SPRAYREQ keywords, to control spraying in the indicator stand. SPRYUNIT and SPRYINDC do not trigger spraying, they identify only the spray block and the indicator stand. If spraying is done in the indicator stand, it will also be done in all of the stands in the spray block. Each stand in the spray block can be sprayed with a unique efficacy by using the EFFICACY keyword within the ADDSTAND—END block.

Example 7: Multistand Spray Run—Enter two stands into the Budworm Dynamics Model; set the starting year to 1990. The second stand entered is the indicator stand, but both stands are within the spray unit.

Reference line	Keyword	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7
1	SPRYUNIT							
2	STARTYR	1990.						
3	ADDSTAND	9.						
4	END							
5	ADDSTAND	9.						
6	SPRAY	1991.	2.					
7	NOSPRAY	1994.						
8	SPRYINDC							
9	END							
10	PROJECT	1995.						
11	STOP							

Line 1: All stands input will be sprayed as a group.

Line 2: Model run will start in 1990.

Lines 3 and 4: Add the first stand to the run.

Line 5: Add the second stand to the run.

Line 6: Activate spraying in year 1991; wait 2 years between sprays.

Line 7: Deactivate spraying in year 1994.

Line 8: Identify the current stand as the indicator stand. Whenever the current stand is sprayed, the first stand will be sprayed as well.

Line 9: End of the second stand.

Line 10: Project the stands for 6 years.

Line 11: Stop the model run.

Representing Silvicultural Actions—The only way to represent silvicultural actions in the Budworm Dynamics Model is to simulate a thinning or regeneration activity prior to writing the foliage files. Recall that by using the WRITEFOL keyword (see Example 2: Using WRITEFOL, page 10), a file describing the stand can be created. This file is entered into the Budworm Dynamics Model using the ADDSTAND keyword. If a thinning is simulated in the same cycle as a WRITEFOL keyword is scheduled, the foliage file will characterize the stand's post-thin condition. Any regeneration activities scheduled for the cycle will not be reflected in the file.

Modifying Biomass Calculations

A component model estimates the potential amount of foliage and an adjusted-potential for each host, crown level, and foliage age class. The potential foliage is the amount of foliage that would be on the tree if it had not been defoliated during the past 5 years. The adjusted-potential reduces the potential to account for a reduced ability of a defoliated tree to produce new foliage. These foliage statistics are passed to the Budworm Dynamics Model via the WRITEFOL and ADDSTAND options. When the Prognosis-Budworm Dynamics Model is being used, these values are passed internally by the computer program.

The adjusted-potential foliage is the amount of biomass in grams that would be found in midsummer (following full shoot growth and leaf expansion) if there is no defoliation during the current year. The Budworm Dynamics Model translates the adjusted-potential new foliage into the number of buds that, given no defoliation, will produce the new foliage biomass (see variable BUDMAS, equation 1, p. 11, Sheehan and others 1989). You may modify the values used to make these conversions using the SHOOTMAS keyword. Lower mass per bud values will provide more budworms with feeding sites initially but may cause more bud or new shoot destruction (also see equation 26, p. 41, Sheehan and others 1989).

A phenology submodel simulates the growth of the shoots from buds to summer biomass. This submodel and accompanying keywords are presented later.

During early larval development, young larvae mine needles, eventually destroying them. Therefore, the number of needles present in each foliage cell is computed by the model. To compute this value, the Budworm Dynamics Model uses a conversion factor for the number of potential grams of fully expanded foliage per needle. You can change these conversion factors using the NEEDLMAS keyword.

The BUDRATIO keyword is used to specify the ratio of reproductive to vegetative buds (see equation 2, p. 14, Sheehan and others 1989). These ratios may be changed by host species and foliage cell. They can be used to simulate good cone versus bad cone years. The REPRDEV keyword is used to enter a slope and intercept for the relationship between the proportion of reproductive buds suitable for larvae to mine and the percentage of shoot expansion (see equation 17, p. 29, Sheehan and others 1989).

The final keyword in this group modifies the relationship between grams of foliage and the number of square meters that biomass represents (see equation 3, p. 16, Sheehan and others 1989). The ratio in grams per square meter can be modified for each host species and foliage cell independently using the GPERM2 keyword.

The keywords in this group are all-stand keywords in the run. You cannot specify, for example, a different biomass to surface area conversion (GPERM2) for different stands.

SHOOTMAS Potential foliage biomass (dry weight) per shoot when fully expanded in the absence of budworm feeding. Default values can be found in table 6. SHOOTMAS is an all-stand keyword.

field 1: Numeric tree species code; required, see table 3.

field 2: Grams per shoot for the upper crowns of small trees.

field 3: Grams per shoot for the midcrowns of small trees.

field 4: Grams per shoot for the lower crowns of small trees.

field 5: Grams per shoot for the upper crowns of medium trees.

field 6: Grams per shoot for the midcrowns of medium trees.

field 7: Grams per shoot for the lower crowns of medium trees.

Supplemental data record:

cols 1-10: Grams per shoot for the upper crowns of large trees.

cols 11-20: Grams per shoot for the midcrowns of large trees.

cols 21-30: Grams per shoot for the lower crowns of large trees.

Table 6—Default values for SHOOTMAS, by crown third (foliage cell) and host (grams per shoot, from table 5, p. 13, Sheehan and others 1989)

Model tree	Crown third	White fir	Douglas-fir	Grand fir	Subalpine fir	Engelmann spruce
Small	upper	0.628	0.493	0.420	0.420	0.493
	mid	.515	.352	.344	.344	.352
	lower	.448	.215	.217	.217	.215
Medium	upper	.628	.493	.420	.420	.493
	mid	.515	.352	.344	.344	.352
	lower	.448	.215	.217	.217	.215
Large	upper	.628	.493	.420	.420	.493
	mid	.515	.352	.344	.344	.352
	lower	.448	.215	.217	.217	.215

NEEDLMAS Potential biomass per needle when full expanded for each host in the absence of budworm feeding. This is an all-stand keyword.

field 1: Grams per needle for white fir; default = 0.013.

field 2: Grams per needle for Douglas-fir; default = 0.005.

field 3: Grams per needle for grand fir; default = 0.009.

field 4: Grams per needle for subalpine fir; default = 0.009.

field 5: Grams per needle for Engelmann spruce; default = 0.005.

BUDRATIO Ratio of reproductive buds to vegetative buds for each host species in grams/shoot. Default values are from table 7, p. 15, Sheehan and others (1989). This is an all-stand keyword.

field 1: Numeric tree species code; required, table 3.

field 2: Ratio for upper crowns of small trees, default = 0.53.

field 3: Ratio for midcrowns of small trees, default = 0.00.

field 4: Ratio for lower crowns of small trees, default = 0.00.

field 5: Ratio for crowns of medium trees, default = 2.10.

field 6: Ratio for midcrowns of medium trees, default = 1.05.

field 7: Ratio for lower crowns of medium trees, default = 0.53.

Supplemental data record:

cols 1-10: Ratio for upper crowns of large trees, default = 2.10.

cols 11-20: Ratio for the midcrowns of large trees, default = 1.05.

cols 21-30: Ratio for the lower crowns of large trees, default = 0.53.

GPERM2 Factor to convert grams of foliage biomass to foliage surface area. For a given host and crown level, the same values are used for each tree size class. Default values are given in table 7. This is an all-stand keyword.

field 1: Numeric tree species codes; required, table 3.

field 2: Grams per square meter foliage for the upper crowns of small trees.

field 3: Grams per square meter foliage for the midcrowns of small trees.

field 4: Grams per square meter foliage for the lower crowns of small trees.

field 5: Grams per square meter foliage for the upper crowns of medium trees.

field 6: Grams per square meter foliage for the midcrowns of medium trees.

field 7: Grams per square meter foliage for the lower crowns of medium trees.

Supplemental data record:

cols 1-10: Grams per square meter foliage for the upper crowns of large trees.

cols 11-20: Grams per square meter foliage for the midcrowns of large trees.

cols 21-30: Grams per square meter foliage for the lower crowns of large trees.

Table 7—Default values for GPERM2 for all tree size classes, by crown third (foliage cell) and host species (grams per square meter, from table 9B, p. 17, Sheehan and others 1989)

Crown third	White fir	Douglas-fir	Grand fir	Subalpine fir	Engelmann spruce
Upper	458	382	458	458	382
Mid	405	409	405	405	409
Lower	352	384	352	352	384

Modifying Dispersal Calculations

The Budworm Dynamics Model represents dispersal of adults, emerging second-instar larvae, and developing larvae. Dispersal assumptions and parameters can be modified as described below.

Adult Dispersal—Budworms disperse between and within stands as adults. A net dispersal factor is used for each stand to account for emigration, immigration, and female adult mortality unless the stand location data is provided through the STNDLOCS keyword and the FLYUNIT keyword is specified. If the Prognosis-Budworm Dynamics Model is being used, net dispersal is the only available option. The FLYUNIT keyword signals that all of subsequent stands that are entered using the ADDSTAND keyword are to be considered within a dispersal area. To specify that a stand not be in the dispersal area, either enter the stand before the FLYUNIT keyword or enter the ENDFLYU keyword. The model will use the net dispersal logic for stands that follow the ENDFLYU keyword.

The STNDLOCS keyword, page 27, directs the model to read a file containing the centroid coordinates and area of each stand to be simulated. When these data are provided, the model can simulate adult female flight between these stands.

If the model encounters problems reading the stand location file, some are missing, or only one stand is to be simulated, the default net dispersal option is used.

FLYUNIT Simulate adult budworm dispersal among all stands following the keyword.

ENDFLYU Stop adding stands to the dispersal set.

When adult dispersal is simulated, a portion of the eggs (egg masses) are laid by the female adults before flight. The default is for each female to lay one egg mass (40.1 eggs) in the stand of origin and for all the remaining eggs to go into a dispersal pool. The EGGPMASS keyword that sets the number of eggs per mass can thus affect this initial deposition of eggs (see equation 3, p. 16, Sheehan and others 1989). It will also affect the egg-mass density statistics in output tables.

The FIRSTEGG keyword allows the user to change the proportion of eggs laid in the stand of origin. This keyword will control the proportion of the total potential egg population laid in the stand of origin. You can also control the number of eggs per female deposited before dispersal begins by adjusting the eggmass size.

The FLYRANGE keyword allows you to change the dispersal range of adult females. All eggs in the dispersal pool from a stand are distributed to all stands within dispersal range according to the proportion of host foliage in a stand relative to all host foliage in all stands within dispersal range.

The PROPMATE keyword allows you to change the proportion of adult females which are successfully fertilized.

All of the adult dispersal keywords are all-stand keywords.

FIRSTEGG   Control simulation of the number of eggs laid by females in their stand of origin.

    field 1:   Index value; 1 = females lay 1 egg mass, 2 = females lay a proportion of their total eggs (enter the proportion in field 2); default = 1.

    field 2:   When the value in field 1 is 2, enter proportion of total eggs that are laid in the stand of origin; default = 0.50.

EGGPMASS   Control the number of eggs per egg mass.

    field 1:   Number of eggs per egg mass laid by adult female budworms; default = 40.1.

FLYRANGE   The dispersing range of adult female budworm.

    field 1:   Maximum dispersal distance in kilometers; default = 25.0 km.

PROPMATE   Specify the proportion of emerging females that will mate and bear eggs. May be used to simulate the effects of mating disruption. This is an all-stand keyword.

    field 1:   Proportion of females mated; default = 1.0.

Spring Dispersal of Emerging Second Instar Larvae—You can control the relative weighting factors for distributing second instar larvae to foliage surface areas in crown thirds using the RELL2DEN keyword (see equation 8, p. 22, Sheehan and others 1989). The IMMDISP keyword is used to control the proportion of second instar larvae (L2's) that disperse immediately after they leave their hibernacula (variable SPDISP, p. 33, Sheehan and others 1989).

RELL2DEN   Relative densities of emerging second instars by foliage cell and host. Default values are from table 12, p. 23, Sheehan and others (1989).

    field 1:   Numeric species code; required, table 3.

    field 2:   Relative densities in the upper crowns of small trees. Default for all tree species is 0.440.

    field 3:   Relative densities in the midcrowns of small trees. Default for all tree species is 0.316.

    field 4:   Relative densities in the lower crowns of small trees. Default for all tree species is 0.243.

	field 5:	Relative densities in the upper crowns of medium trees. Default for all tree species is 0.440.
	field 6:	Relative densities in the midcrowns of medium trees. Default for all tree species is 0.316.
	field 7:	Relative densities in the lower crowns of medium trees. Default for all tree species is 0.243.

Supplemental data record:

	cols 1-10:	Relative densities in the upper crowns of large trees. Default for all tree species is 0.440.
	cols 11-20:	Relative densities in the midcrowns of large trees. Default for all tree species is 0.316.
	cols 21-30:	Relative densities in the lower crowns of large trees. Default for all tree species is 0.243.
IMMDISP	field 1:	Enter the proportion of second instar larvae that disperse immediately after they leave their hibernacula; default = 0.80 (Sheehan and others 1989 used 0.05 as the default).

Developing Larval Dispersal—Larval dispersal is simulated every 20-degree-day step. Second instars emerging from hibernacula are distributed first. A portion of these are assumed to disperse immediately from each foliage cell. The IMMDISP keyword can be used to change this proportion. Young larvae will mine needles if buds have not sufficiently expanded to allow larvae to penetrate the budcap and begin feeding. The L2DISP keyword can be used to control the proportion that mine needles rather than disperse from a foliage cell.

In the absence of new foliage, older larvae may disperse or feed on old foliage. The BACKFEED keyword is used to specify the proportion of larvae that disperse.

Once a dispersing pool has been established for each cell, a portion are dispersed to non-foliage. The remaining are assumed to land on foliage (both host and non-host). The number not finding foliage is a function of the amount of foliage present in the stand (see fig. 9, p. 44, Sheehan and others 1989). The more foliage present in the stand, the less likely budworm are to disperse off foliage. The DISPNFOL keyword allows you to change the parameters of this function (variables DASYM, DISERT, and FBELOW in equation 27, p. 43, Sheehan and others 1989).

Two competing factors affect the final location (foliage cell) of larvae that disperse onto foliage. Each instar is assumed to have preferred travel directions (up, lateral, down). These directions are combined with the number of foliage cells in each direction to determine distribution between destination foliage cells. The DISPDIR keyword allows you to redistribute between these directions for each instar (variable CPREF in equation 28, p. 43, Sheehan and others 1989). The second factor is the amount of foliage in each foliage cell. The dispersing larvae are also partitioned according to the amount of foliage in each foliage cell (host and non-host). By default, these two factors (directional preference and foliage distribution) are weighted equally. The DIRWT keyword allows you to change the relative weights of these two factors (variable CRWNWT in equations 29 and 30, p. 46, Sheehan and others 1989).

L2DISP	field 1:	Specify the proportion of emerging second-instar (L2) budworm that disperse rather than mine needles if they cannot find buds, default = 0.50.
DIRWT		Weight given instar-specific directional preference versus foliage biomass per foliage cell when calculating dispersal destination. Weight given foliage biomass is the complement of the value coded in field 1.

	field 1:	Weight given directional preference, default = 0.50; must be between 0.0 and 1.0.

DISPDIR   Proportion of dispersing larvae that will travel in a particular direction by instar. Default values are contained in table 8.

         field 1:   Instar numeric code as shown in table 9, no default.

         field 2:   Proportion of budworms that will disperse by moving down.

         field 3:   Proportion of budworms that will disperse by moving in a lateral direction.

         field 4:   Proportion of budworms that will disperse by moving up.

Table 8—Default values for DISPDIR by instar and direction (modified table 22, p. 45, Sheehan and others 1989)

Instar	Value in field 1	Direction of movement		
		Down (field 2)	Lateral (field 3)	Up (field 4)
Second	2	0.05	0.10	0.85
Third	3	.10	.20	.70
Fourth	4	.20	.30	.50
Fifth	5	.20	.30	.50
Sixth	6	.20	.30	.50

Table 9—Default values for BACKFEED by host tree species and budworm instar (modified table 19, p. 37, Sheehan and others 1989)

Instar	White fir	Douglas-fir	Grand fir	Subalpine fir	Engelmann spruce
Second	0.22	0.08	0.22	0.14	0.08
Third	.44	.16	.44	.28	.16
Fourth	.44	.16	.44	.24	.16
Fifth	.68	.12	.68	.60	.12
Sixth	.83	.88	.83	.64	.88

BACKFEED   Specify the proportion of larvae by host tree species that feed on older foliage rather than disperse when new foliage is not available. Default values can be found in table 9. This is an all-stand keyword.

         field 1:   Numeric species code; required, table 3.

         field 2:   Proportion of second instar larvae that backfeed.

         field 3:   Proportion of third instar larvae that backfeed.

         field 4:   Proportion of fourth instar larvae that backfeed.

         field 5:   Proportion of fifth instar larvae that backfeed.

         field 6:   Proportion of sixth instar larvae that backfeed.

DISPNFOL   Parameters for the relationship between total foliage below and lateral to the original foliage cell of dispersing larvae and proportion of those larvae that are killed because they land on non-foliage.

field 1:   Lower asymptote, default = 0.05.

field 2:   Intercept; default = 0.75.

field 3:   Exponential function slope = –0.0000006/gram.

Modifying Mortality Calculations

Budworms are subject to mortality at every stage in their life. The model represents dispersal mortality and several other natural causes of mortality. Direct population suppression is another source of mortality. This source has already been described.

Dispersal Mortality—You have just been introduced to means of controlling larval dispersal during each 20-degree-day step. All those larvae that disperse to non-foliage or non-hosts trees are assumed to die.

During adult dispersal, a portion of the adults are assumed to die thereby killing the potential eggs they carry. When the net-dispersal option is used, the DISNET keyword can be used to specify a specific survival rate for female adults in each stand (p. 53, Sheehan and others 1989). When using the Prognosis-Budworm Dynamics Model, this keyword must contain an appropriate date to have the option properly scheduled.

The adult dispersal model simulates adult female flight between stands. Adult female mortality increases as the average foliage density (suitable sites to lay egg masses) over all the stands that are within dispersing distance decreases. The relation between medium foliage density (square meter per hectare) and adult mortality can be altered using the FLYMORT keyword (see equation 38, p. 54, Sheehan and others 1989).

As budworm emerge from eggs, they disperse to overwintering sites, spin hibernaculae and moult to second instar. The model assumes a fixed mortality rate for fall and overwinter. The FLOWMORT keyword can be used to alter this parameter. In addition, a portion of the second-instar budworms emerging from overwintering sites die as they search for initial feeding sites. The SPRMORT keyword can be used to alter this parameter. (See variables FALLOW and SPRGND in equation 7, p. 21, Sheehan and others 1989.)

DISNET   Select a survival rate for dispersing adult females (potential eggs) in this stand when using the net dispersal option.

field 1:   Year to schedule this option in the Prognosis-Budworm Dynamics Model (default = cycle 1).

field 2:   Net survival rate; default = 0.8 (80 percent of the potential eggs survive the effects of adult dispersal).

FLYMORT   Specify the slope and intercept for the relationship between mean host foliage (square meters per hectare) and adult mortality during dispersal.

field 1:   Lower asymptote, default = 0.2.

field 2:   Intercept, default = 0.75.

field 3:   Exponential function slope, default = –0.0002.

FLOWMORT   Specify the proportion of first-instar budworms that die during fall dispersal or during overwintering in hibernacula.

field 1:   Proportion of first or second instar budworms that die during fall dispersal or during overwintering; default = 0.55.

SPRMORT   Enter a net spring mortality rate to account for spring dispersal to initial feeding sites. Further dispersal mortality will occur as feeding larvae move between foliage cells.

field 1:   Proportion of second instar budworms that die during spring dispersal to feeding sites; default = 0.30.

Other Natural Mortality—Two factors affect egg survival; both can be changed through keywords. EGGNONV will allow you to change the proportion of eggs that are assumed to be non-viable. EGGPARA will allow you to change the proportion of eggs that are assumed to be killed by parasites (see p. 19, Sheehan and others 1989).

Two groups of predators—birds and ants—are modeled. Ant predation rates are different in each of three height strata. The ANTHT keyword allows you to change the height boundaries that define the stand canopy strata and the ANTSURV keyword allows you to change the budworm survival rates associated with ant predation (see p. 50, Sheehan and others 1989).

Five bird guilds are modeled separately, and the total mortality from birds is distributed between two stand canopy strata. The BIRDDEN keyword provides a means of changing the basic bird census statistics given in total biomass per hectare for each guild for four stand successional stages (see equation 32, p. 47, Sheehan and others 1989). BIRDHRS sets the number of foraging hours per day for birds in all guilds (variable HPDAY in equation 33, p. 49, Sheehan and others 1989).

The bird-caused budworm mortality is not distributed evenly between all foliage cells. Forty percent of this mortality is in the lower canopy, and 60 percent is in the upper canopy (see equation 34, p. 50, Sheehan and others 1989). BIRDHT changes the boundary (meters) level between these canopy strata levels.

BIRDMULT is a multiplication factor to account for the fact that bird censuses do not account for nestlings or fledglings, only adults (see equation 32, p. 47, Sheehan and others 1989).

The HIDEBW keyword allows you to change the portion of the budworm population that is effectively hidden from natural enemies during a 20-degree-day step.

The effects of foliage quality on budworm mortality and weight gain are controled using the FOLQUAL and USEFOLQ keywords (see equation 22, p. 38, and p. 52, Sheehan and others 1989). These effects depend on the habitat type and host species. For example, if a subalpine fir tree is growing on a grand fir habitat type, then the model assumes that the tree is growing under some stress and therefore its foliage is better for budworms than subalpine fir foliage growing on a subalpine fir habitat series. The stand habitat type code entered using the Prognosis Model's STDINFO keyword is translated into habitat series codes using a translation table (table 10).

Parasitization of budworms is modeled as described on page 51 of Sheehan and others (1989). But keywords are not provided to change the default parasitization rates.

Table 10—Habitat type translation to habitat series numeric code

Habitat type code	Series code	Series name
0 – 399	1	Douglas–fir
400 – 499	2	Grand fir
500 – 529	3	Engelmann spruce
530 – 599	4	Subalpine fir
600 – 999	5	Western redcedar

EGGNONV   field 1:   Proportion of budworm eggs which are non-viable; default = 0.054.

EGGPARA   field 1:   Egg parasitization rate, default = 0.025.

ANTSURV   Budworm survival rate from ants during each 20-degree-day interval for three strata of stand canopy.

	field 1:	Budworm survival rate from ants in the top canopy stratum, default = 1.00.

field 1: Budworm survival rate from ants in the top canopy stratum, default = 1.00.

field 2: Budworm survival rate from ants in the middle canopy stratum, default = 0.9968.

field 3: Budworm survival rate from ants in the bottom canopy stratum, default = 0.9932.

ANTHT Change boundary used to distribute total budworm mortality from ant predation between canopy layers.

field 1: Boundary between the upper and middle stand canopy strata in meters; default = 10.0.

field 2: Boundary between the lower and middle stand canopy strata in meters; default = 7.0.

BIRDHT Change boundary used to distribute total budworm mortality from bird predation between upper canopy (40 percent) and lower canopy (60 percent).

field 1: Boundary between two stand canopy strata in meters; default = 10.0.

BIRDHRS Number of foraging hours per day for birds in all guilds.

field 1: Foraging hours per day; default = 16.0.

BIRDMULT Number of birds represented by each recorded bird in surveys (includes nestlings, nonsinging males, etc.).

field 1: Bird multiplier; default = 2.5.

BIRDDEN Change the biomass per hectare (grams per hectare) of each bird guild for each stand successional stage. See table 11 for default values.

field 1: Stand successional stage index, enter 1 for grass-shrub stage, 2 for shrub-tree stage, 3 for seral-tree stage, or 4 for old-growth stage (default = 1).

field 2: Biomass per hectare of guild 1, ground foragers.

field 3: Biomass per hectare of guild 2, shrub gleaners.

field 4: Biomass per hectare of guild 3, flockers.

field 5: Biomass per hectare of guild 4, foliage gleaners.

field 6: Biomass per hectare of guild 5, flycatchers.

Table 11—Total biomass (grams per hectare) of all birds in each of the five major guilds of budworm-consuming birds for four stand successional stages and the medium biomass per bird for each guild (from table 25, p. 49, Sheehan and others 1989)

Bird guild	Biomass per bird	Successional stages			
		Grass-shrub	Shrub-tree	Seral tree	Old-growth
Ground forager	11.6	26.04	62.340	23.840	19.160
Shrub gleaner	7.4	.65	9.560	.836	.040
Flocker	10.6	1.35	.262	.979	2.660
Foliage gleaner	7.4	8.24	19.310	11.660	24.030
Flycatcher	7.4	1.49	3.770	1.590	2.350

HIDEBW	field 1:	The proportion of the budworm population that is effectively hidden from predators and parasites each 20-degree-day step; default = 0.10.

FOLQUAL   Multipliers that represent the effects of foliage quality on budworm survival and weight gain. The multipliers are indexed by habitat series and host species. Default values can be found in table 12. This is an all-stand keyword.

field 1:   Habitat series numeric code, see table 10, no default.

field 2:   Multiplier for foliage quality on white fir.

field 3:   Multiplier for foliage quality on Douglas-fir.

field 4:   Multiplier for foliage quality of grand fir.

field 5:   Multiplier for foliage quality of subalpine fir.

field 6:   Multiplier for foliage quality of Engelmann spruce.

Table 12—Default multipliers for FOLQUAL keyword (values are altered from table 21, p. 40, Sheehan and others 1989)

Habitat series	Value of field 1	Host species				
		White fir	Douglas-fir	Grand fir	Subalpine fir	Engelmann spruce
Douglas-fir	1	1.0	0.9	1.0	1.0	1.0
Grand fir	2	.9	.8	.9	1.0	1.0
Engelmann spruce	3	.8	.7	.8	.9	.9
Subalpine fir	4	.7	.8	.7	.8	.8
Western redcedar	5	.6	.6	.7	.7	.8

USEFOLQ   Turn on the use of values found in table 12.

field 1:   Apply FOLQUAL values to weight gain calculations if any numeric value is entered.

field 2:   Apply FOLQUAL values to survival calculations if any numeric value is entered.

Modifying Phenology Calculations

Phenology is the relation between heat accumulation and growth. Heat accumulation is measured in terms of the daily maximum and minimum ambient temperatures adjusted by upper and lower thresholds for heat accumulation (degree-days). Budworm and host phenology are modeled separately. Both are based on daily maximum and minimum temperatures provided by the Weather Model. Here we provide means to alter many of the assumptions used in these phenology models.

Budworm Phenology—The budworm phenology model controls budworm emergence from hibernacula and the growth of individual budworm cohorts from second instar through the pupal stage. The BWHITH and BWLOTH keywords allow you to reset the upper and lower temperature thresholds used in accumulating heat units (degree-days) (see equation 9, p. 24, Sheehan and others 1989). BWSTART allows you to change the Julian date used to start accumulating degree-days. MINDDAY allows you to change the heat accumulation required before second-instar larvae begin to emerge from hibernacula.

The EMERGPAT keyword allows you to adjust the temporal pattern of second-instar emergence (see equation 18, p. 32, Sheehan and others 1989). FEMDEV and MALEDEV allow you to change the number of 20-degree-day time steps required to accumulate for individual female or male budworm to complete the second-instar through pupal stages (see table 15B, p. 31, Sheehan and others 1989).

BWHITHR   Specify the upper threshold of development for budworms.

                field 1:   Temperature; default = 37.8 °C (100 °F).

BWLOTHR   Specify the lower threshold of development for budworms.

                field 1:   Temperature; default = 5.5 °C (42 °F).

BWSTART   Specify the Julian day when degree days may start accumulating for budworms.

                field 1:   Julian date; default = 91 (April 1).

MINDDAY   Specify the minimum number of accumulated degree days required before second instar budworms emerge from hibernaculae; default = 68.

EMERGPAT   Specify the temporal pattern of budworm emergence from hibernacula. It is assumed that emergence can occur over a period of up to fifteen 20-degree-day steps each spring.

                field 1:   Proportion emerging during interval 1; default = 0.01.

                field 2:   Proportion emerging during interval 2; default = 0.12.

                field 3:   Proportion emerging during interval 3; default = 0.20.

                field 4:   Proportion emerging during interval 4; default = 0.21.

                field 5:   Proportion emerging during interval 5; default = 0.18.

                field 6:   Proportion emerging during interval 6; default = 0.11.

                field 7:   Proportion emerging during interval 7; default = 0.07.

                Supplemental data record:

                cols 1-10:   Proportion emerging during interval 8; default = 0.04.

                cols 11-20:   Proportion emerging during interval 9; default = 0.03.

                cols 21-30:   Proportion emerging during interval 10; default = 0.02.

                cols 31-40:   Proportion emerging during interval 11; default = 0.01.

                cols 41-50:   Proportion emerging during interval 12; default = 0.00.

                cols 51-60:   Proportion emerging during interval 13; default = 0.00.

                cols 61-70:   Proportion emerging during interval 14; default = 0.00.

                cols 71-80:   Proportion emerging during interval 15; default = 0.00.

FEMDEV   Specify the number of 20-degree-day intervals per life stage for
MALEDEV   females (FEMDEV) and males (MALEDEV). If either of these keywords are used, there must be no blank fields. The total number of intervals must be less than 50.

                field 1:   Intervals for second instar budworm; default for both sexes is five intervals.

                field 2:   Intervals for third instar budworm; default for both sexes is three intervals.

                field 3:   Intervals for fourth instar budworm; default for both sexes is four intervals.

field 4: Intervals for fifth instar budworm; default for both sexes is four intervals.

field 5: Intervals for sixth instar budworm; default for both sexes is six intervals.

field 6: Intervals for pupae; default for both sexes is nine intervals.

Foliage Phenology—Host foliage phenology models are used to grow buds into new foliage (current year's growth). The Budworm Dynamics Model starts with potential summer foliage biomass predicted by Prognosis (supplied in the foliage file). It converts this into the number of buds in each foliage cell of each host needed to grow this potential summer biomass. The foliage phenology models then grow each bud according to heat (degree-days) accumulation. The HOSTHIGH and HOSTLOW keywords provide access to the upper and lower thresholds for each host (see equation 10, p. 24, Sheehan and others 1989). The HOSTART keyword allows you to change the Julian date used to start this heat accumulation. Other model parameters described by Sheehan (1989, p. 26-27) cannot be changed by keyword.

HOSTHIGH Specify the upper development threshold for hosts. All defaults = 35 °C, (95 °F). Default values are used if blank fields are present on the keyword card.

field 1: Temperature for white fir.

field 2: Temperature for Douglas-fir.

field 3: Temperature for grand fir.

field 4: Temperature for subalpine fir.

field 5: Temperature for Engelmann spruce.

HOSTLOW Specify the lower development threshold for hosts. All defaults = 5.5 °C, (42 °F). Default values are used if blank fields are present on the keyword card.

field 1: Temperature for white fir.

field 2: Temperature for Douglas-fir.

field 3: Temperature for grand fir.

field 4: Temperature for subalpine fir.

field 5: Temperature for Engelmann spruce.

HOSTART Specify the Julian day when degree days may start accumulating for budworm hosts; all defaults = 121 (May 1).

field 1: Julian date for white fir.

field 2: Julian date for Douglas-fir.

field 3: Julian date for grand fir.

field 4: Julian date for subalpine fir.

field 5: Julian date for Engelmann spruce.

Modifying Feeding Calculations

Several processes interact as budworm feed. Buds must be sufficiently developed to allow emerging larvae to penetrate them and begin feeding. If bud development is not sufficient, young larvae mine older needles or disperse. Bud-mining budworms may kill individual buds before the buds have a chance to open. As foliage and budworms develop, budworms eat more and are better able to consume older foliage. Budworm prefer new foliage and will attempt to consume all new foliage before feeding on old foliage. Budworm are sloppy eaters; they do not actually consume all the foliage they destroy.

Fifteen keywords are available allowing you to change feeding parameters. HIDEBUD and HIDEFOL provide a means to change the proportion of total buds or foliage that is effectively hidden from budworm in each 20-degree-day time step (Sheehan and others 1989, pp. 33 and 36).

BUDKILL allows you to change the relation between bud development and the amount of defoliation that will kill buds (variable DEFMIN, equation 25, p. 41, Sheehan and others 1989). When buds are damaged early in the growing season, foliage that would have been grown by expanding shoots is also lost. The SHOOTMAS keyword (page 31, see table 5) allows you to alter the foliage produced per bud (variable BUDMAS as used in equation 26, p. 41, Sheehan and others 1989). You also have the ability to modify the relationship between the proportion of shoot expansion and the proportion of buds suitable for mining (the REPRDEV and VEGDEV keywords, see equations 16 and 17, p. 29, Sheehan and others 1989).

Male and female budworm have been shown to have instar and sex-specific consumption rates that differ for current growth and older foliage. FNEWFEED, MNEWFEED, FOLDFEED, and MOLDFEED keywords allow you to manipulate the consumption rates (see equation 19, p. 34, and equation 22, p. 38, Sheehan and others 1989).

Keywords allow you to change relation between the amount of foliage (new or old) consumed and that destroyed by stipulating the proportions wasted during each instar for a host. Use the MWASTEDN, FWASTEDN, MWASTEO, or FWASTEDO keywords (see equation 19, p. 34, Sheehan and others 1989).

The conversion of foliage biomass to budworm biomass differs between new and old foliage and by host species. The CONVNEW and CONVOLD keywords allow you to control these conversion rates (variables ECIF and ECIBFF in equation 22, p. 38, Sheehan and others 1989).

HIDEBUD Specify the proportion of buds that are effectively hidden (protected from mining) from budworms during a given 20-degree-day interval.

field 1: Proportion of hidden buds during any time step; default = 0.10.

HIDEFOL Specify the proportion of foliage that is effectively hidden from budworm during each 20-degree-day interval.

field 1: Proportion of hidden foliage during any time step; default = 0.10.

BUDKILL Specify the minimum percent defoliation and maximum percent shoot expansion allowed when bud killing occurs.

field 1: Percent defoliation allowed when bud killing occurs; default = 30. If defoliation in a foliage cell is 30 percent and the shoots are less than 5 percent expanded (field 2), then a portion of the buds will be killed.

field 2: Maximum percent shoot expansion allowed when bud killing occurs; default = 5.

REPRDEV Slope and intercept for the linear relationship between proportion of reproductive buds suitable for mining and percentage of shoot expansion of vegetative buds.

field 1: Slope; default = 0.0.

field 2: Intercept; default = 1.0.

VEGDEV Specify the slope and intercept of the linear relationship between proportion of average vegetative bud development and bud availability for budworm mining (proportion of bud population that are available for mining).

field 1:   Slope; default = 1.0.

field 2:   Intercept; default = 0.0.

FNEWFEED   Specify the amount of new foliage (grams) by host tree species consumed by each female budworm larva during a 20-degree-day period. Default values are found in table 13. This is an all-stand keyword.

field 1:   Numeric species code; required, table 3.

field 2:   Grams of new foliage consumed by second-instar female budworms.

field 3:   Grams of new foliage consumed by third-instar female budworms.

field 4:   Grams of new foliage consumed by fourth-instar female budworms.

field 5:   Grams of new foliage consumed by fifth-instar female budworms.

field 6:   Grams of new foliage consumed by sixth-instar female budworms.

Table 13—Default values for FNEWFEED by host tree species and budworm instar (from table 17, p. 35, Sheehan and others 1989)

Instar	White fir	Douglas-fir	Grand fir	Subalpine fir	Engelmann spruce
Second	0.0013	0.0010	0.0011	0.0010	0.0010
Third	.0026	.0026	.0028	.0026	.0026
Fourth	.0042	.0033	.0035	.0033	.0033
Fifth	.0212	.0163	.0178	.0167	.0166
Sixth	.0241	.0189	.0200	.0189	.0189

FOLDFEED   Amount of older foliage (grams) by host tree species consumed by each female budworm during a 20-degree-day period. Default values can be found in table 14. This is an all-stand keyword.

field 1:   Numeric species code; required, table 3.

field 2:   Grams of old foliage consumed by second-instar female budworm.

field 3:   Grams of old foliage consumed by third-instar female budworm.

field 4:   Grams of old foliage consumed by fourth-instar female budworm.

field 5:   Grams of old foliage consumed by fifth-instar female budworm.

field 6:   Grams of old foliage consumed by sixth-instar female budworm.

MNEWFEED   Specify the amount of new foliage (grams) by host tree species consumed by each male budworm larva during a 20-degree-day period. Default values can be found in table 15. This is an all-stand keyword.

field 1: Numeric species code; required, table 3.

field 2: Grams of new foliage consumed by second-instar male budworm.

field 3: Grams of new foliage consumed by third-instar male budworm.

field 4: Grams of new foliage consumed by fourth-instar male budworm.

field 5: Grams of new foliage consumed by fifth-instar male budworm.

field 6: Grams of new foliage consumed by sixth-instar male budworm.

Table 14—Default values for FOLDFEED by host tree species and budworm instar (from table 17, p. 35, Sheehan and others 1989)

Instar	White fir	Douglas-fir	Grand fir	Subalpine fir	Engelmann spruce
Second	0.0016	0.0013	0.0014	0.0013	0.0013
Third	.0033	.0033	.0035	.0033	.0033
Fourth	.0053	.0041	.0045	.0053	.0053
Fifth	.0265	.0208	.0228	.0208	.0208
Sixth	.0301	.0236	.0258	.0236	.0236

Table 15—Default values for MNEWFEED by host tree species and budworm instar (from table 17, p. 35, Sheehan and others 1989)

Instar	White fir	Douglas-fir	Grand fir	Subalpine fir	Engelmann spruce
Second	0.0008	0.0007	0.0007	0.0008	0.0007
Third	.0021	.0017	.0018	.0021	.0017
Fourth	.0026	.0022	.0023	.0026	.0022
Fifth	.0166	.0138	.0145	.0166	.0138
Sixth	.0200	.0166	.0175	.0200	.0166

MOLDFEED   Specify the amount of older foliage (grams) by host tree species consumed by each male budworm during a 20-degree-day period. Default values can be found in table 16. This is an all-stand keyword.

field 1: Numeric species code; required, table 3.

field 2: Grams of old foliage consumed by second-instar male budworm.

field 3: Grams of old foliage consumed by third-instar male budworm.

field 4: Grams of old foliage consumed by fourth-instar male budworm.

field 5: Grams of old foliage consumed by fifth-instar male budworm.

field 6: Grams of old foliage consumed by sixth-instar male budworm.

Table 16—Default values for MOLDFEED by host tree species and budworm instar (from table 17, p. 35, Sheehan and others 1989)

Instar	White fir	Douglas-fir	Grand fir	Subalpine fir	Engelmann spruce
Second	0.0010	0.0009	0.0009	0.0010	0.0009
Third	.0026	.0021	.0023	.0026	.0021
Fourth	.0033	.0028	.0029	.0033	.0028
Fifth	.0208	.0173	.0181	.0208	.0173
Sixth	.0250	.0208	.0219	.0250	.0208

FWASTEDN   Proportion of total new foliage destroyed that is wasted (clipped but not consumed) by female budworm larvae for each host tree species. Default values can be found in table 17. This is an all-stand keyword.

field 1:   Numeric species code; required, table 3.

field 2:   Proportion of new foliage destroyed that is wasted by second-instar female budworm.

field 3:   Proportion of new foliage destroyed that is wasted by third-instar female budworm.

field 4:   Proportion of new foliage destroyed that is wasted by fourth-instar female budworm.

field 5:   Proportion of new foliage destroyed that is wasted by fifth-instar female budworm.

field 6:   Proportion of new foliage destroyed that is wasted by sixth-instar female budworm.

Table 17—Default values for foliage waste keywords (from table 18B, p. 36, Sheehan and others 1989)

Instar	FWASTEDN and MWASTEDN	FWASTEDO and MWASTEDO
Second	0.50	0.59
Third	.60	.65
Fourth	.67	.72
Fifth	.71	.75
Sixth	.75	.79

FWASTEDO   Specify the proportion of total older foliage destroyed that is wasted (clipped but not consumed) by female budworm larvae for each host tree species. Default values can be found in table 17. This is an all-stand keyword.

field 1:   Numeric species code; required, table 3.

field 2:   Proportion of old foliage destroyed that is wasted by second-instar female budworm.

field 3:   Proportion of old foliage destroyed that is wasted by third-instar female budworm.

field 4:   Proportion of old foliage destroyed that is wasted by fourth-instar female budworm.

	field 5:	Proportion of old foliage destroyed that is wasted by fifth-instar female budworm.
	field 6:	Proportion of old foliage destroyed that is wasted by sixth-instar female budworm.
MWASTEDN		Specify the proportion of total new foliage destroyed that is wasted (clipped but not consumed) by male budworm larvae for each host tree species. Default values can be found in table 17. This is an all-stand keyword.
	field 1:	Numeric species code; required, table 3.
	field 2:	Proportion of new foliage destroyed that is wasted by second-instar male budworm.
	field 3:	Proportion of new foliage destroyed that is wasted by third-instar male budworm.
	field 4:	Proportion of new foliage destroyed that is wasted by fourth-instar male budworm.
	field 5:	Proportion of new foliage destroyed that is wasted by fifth-instar male budworm.
	field 6:	Proportion of new foliage destroyed that is wasted by sixth-instar male budworm.
MWASTEDO		Specify the proportion of total older foliage destroyed that is wasted (clipped but not consumed) by male budworm larvae for each host species. Default values can be found in table 17. This is an all-stand keyword.
	field 1:	Numeric species code; required, table 3.
	field 2:	Proportion of old foliage destroyed that is wasted by second-instar male budworm.
	field 3:	Proportion of old foliage destroyed that is wasted by third-instar male budworm.
	field 4:	Proportion of old foliage destroyed that is wasted by fourth-instar male budworm.
	field 5:	Proportion of old foliage destroyed that is wasted by fifth-instar male budworm.
	field 6:	Proportion of old foliage destroyed that is wasted by sixth-instar male budworm.
CONVNEW		Instar-specific conversion rate for new foliage biomass (grams) consumed (dry weight) to female biomass (grams) gain (dry weight) for each host species. Default values can be found in table 18. This is an all-stand keyword.
	field 1:	Numeric species code; required, table 3.
	field 2:	Second-instar conversion rate.
	field 3:	Third-instar conversion rate.
	field 4:	Fourth-instar conversion rate.
	field 5:	Fifth-instar conversion rate.
	field 6:	Sixth-instar conversion rate.

CONVOLD Instar-specific conversion rate for older foliage biomass (grams) consumed (dry weight) to female biomass (grams) gain (dry weight) for each host species. Default values can be found in table 18. This is an all-stand keyword.

field 1:   Numeric species code; required, table 3.

field 2:   Second-instar conversion rate.

field 3:   Third-instar conversion rate.

field 4:   Fourth-instar conversion rate.

field 5:   Fifth-instar conversion rate.

field 6:   Sixth-instar conversion rate.

Table 18—Default values for CONVNEW and CONVOLD for all instars by host species (from table 20, p. 39, Sheehan and others 1989)

Keyword	White fir	Douglas-fir	Grand fir	Subalpine fir	Engelmann spruce
CONVNEW	0.0583	0.0878	0.0583	0.0640	0.0878
CONVOLD	.0437	.0659	.0437	.0480	.0659

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APPENDIX A: EXAMPLE RUNS

Keyword files are provided illustrating how to accomplish specific tasks. Read the keyword files, particularly the comments. Examples include the following:

1. Using the Prognosis-Budworm Dynamics Model to simulate the growth of a stand.

    a. Enter budworm defoliation levels using DEFOL keywords; see example A-1. This can be done using the Prognosis-Budworm Dynamics Model or the Prognosis-Budworm Damage Model.

    b. Use the Budworm Dynamics Model (CALLBW); see example A-2. This can only be done using the Prognosis-Budworm Dynamics Model.

    c. Create foliage description files for use in the budworm model (WRITEFOL); see example A-3. This can be done using the Prognosis-Budworm Dynamics Model or the Prognosis-Budworm Damage Model.

2. Use the Budworm Dynamics Model to simulate population dynamics on a group of stands; see example A-4.

Using the Prognosis-Budworm Dynamics Model

The tree data used in examples A-1, A-2, and A-3 are illustrated in figure A-1.

```
----+----1----+----2----+----3----+----4----
040101003521012021163     03067 3229993
040101003521022025043     99995 9999994
040101003521032021220     02087 2229993
040101003521042021152     12145 8529993
040101003522012021038     05055 9999994
040101003522022021108     02106 5419993301
040101003522032021045     02205 9999994
040101003522042021096     01475 9999993
040101003522052025041     99996 9999994305
040101003522062021021     02425 999   5306
040101003522061221415         1
040101003523012021174067000006 0112333304
040101003523022021098042010055 3229994302
040101003523032021149074020055 4229993301
040101003523042021209075020076 3229993301
040101003523052021150061031393 4329993303
040101003523062021101057091593 5329993303
040101003525012021060     00003 3229993306
040101003525022021089     10125 5449993306
040101003525032021083     00084 8779993306
040101003525042021140     02045 4339993303
040101003525052021109     00027 9999993305
040101003525062021126     01075 6659993303
040101003525072027008     99996 999999 304
04010100352507122 464         1
```

Figure A-1—Tree data file BEAR01.TREES. Similar data files, called BEAR02.TREES and BEAR03.TREES, are used in the examples presented in this appendix.

Example A-1: Using DEFOL Keywords—Read the comments in the examples.

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----
COMMENT
--------------------------------------------------------------------------------
Set the number of cycles and enter stand and management identifications.  If
the projection is on the first cycle, then schedule the DEFOL options.  Note
that the WSBW keyword is used to signal that Budworm Model options follow in
the file.  Only activities (those with a year or cycle number in the first
field) are affected by the logical expression.  The DAMAGE keyword is used to
request damage output.  OPEN is used to open a data set referenced by the
number 44 as file named STATDATA.  The following record is a STATDATA keyword
with 44 coded in fields 3 and 4; the annual and period damage output is
therefore written to the file called STATDATA.
--------------------------------------------------------------------------------
END
NUMCYCLE   10.
STDIDENT
BEAR01
MGMTID
M013
IF
CYCLE EQ 1
THEN
WSBW
DAMAGE
OPEN        44.                                  130.
STATDATA.OUT
STATDATA                             44.         44.
DEFOL            0.        3.        0.          10.
DEFOL            1.        3.        0.          40.
DEFOL            2.        3.        0.          70.                        15.
DEFOL            3.        3.        0.          85.                        15.
DEFOL            4.        3.        0.          85.                        15.
DEFOL            5.        3.        0.          85.                        15.
DEFOL            6.        3.        0.          85.                        15.
DEFOL            7.        3.        0.          50.                        15.
DEFOL            8.        3.        0.          20.                         5.
DEFOL            9.        3.        0.          10.                         5.
DEFOL            0.        4.        0.          20.
DEFOL            1.        4.        0.          50.
DEFOL            2.        4.        0.          80.
DEFOL            3.        4.        0.          90.
DEFOL            4.        4.        0.          90.
DEFOL            5.        4.        0.          90.                         2.
DEFOL            6.        4.        0.          90.                         5.
DEFOL            7.        4.        0.          50.                         1.
DEFOL            8.        4.        0.          20.                         1.
DEFOL            9.        4.        0.          10.                         1.
END
ENDIF
COMMENT
--------------------------------------------------------------------------------
The end of the budworm options are indicated by an END, the end of the options
that are conditionally scheduled are marked with an ENDIF.  The following
keywords are used to enter stand site specific data, the inventory design,
alternative species codes, and the tree data format specification.  See Wykoff
and others (1982) for a further description of these keywords.
--------------------------------------------------------------------------------
END
STDINFO      7.       310.                 1.        6.        51.
INVYEAR    1986.
DESIGN       20.      300.        3.
SPCODES
119 073 202 017 263 242 108 093 019 122
TREEFMT
(T11,I2,T50,F1.0,T51,I1,T15,A3,T19,F3.1,T52,F1.0,T22,F3.0,T53,2F1.0,T29,
I1,T54,I1,T4,2I1)
OPEN         45.
BEAR01.TREES
TREEDATA     45.
CLOSE        45.
PROCESS
STOP
```

Example A-2 Using CALLBW—

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----
COMMENT
--------------------------------------------------------------------------------
Set the number of cycles and enter stand and management identifications.  If
the projection is on the first cycle, then schedule the CALLBW option.
--------------------------------------------------------------------------------
END
NUMCYCLE    10.
STDIDENT
BEAR01
MGMTID
C013
IF
CYCLE EQ 1
THEN
WSBW
CALLBW             0.
END
ENDIF
STDINFO        7.      310.                   1.       6.       51.
INVYEAR     1986.
DESIGN        20.      300.        3.
SPCODES
119 073 202 017 263 242 108 093 019 122
TREEFMT
(T11,I2,T50,F1.0,T51,I1,T15,A3,T19,F3.1,T52,F1.0,T22,F3.0,T53,2F1.0,T29,
I1,T54,I1,T4,2I1)
OPEN          45.
BEAR01.TREES
TREEDATA      45.
CLOSE         45.
PROCESS
STOP
```

Example A-3. Using WRITEFOL—This keyword file is used to create the file BEAR01.WRITEFOL, illustrated in figure A-2. Similar files are used to create files BEAR02.WRITEFOL and BEAR03.WRITEFOL used in example A-4.

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----
COMMENT
--------------------------------------------------------------------------------
Set the number of cycles to 1.0 and schedule the WRITEFOL.
--------------------------------------------------------------------------------
END
NUMCYCLE   1.
STDIDENT
BEAR01     West end of Bear Gulch, Malheur National Forest, Oregon.
OPEN        22.
BEAR01.WRITEFOL
THEN
WSBW
WRITEFOL   1986.      22.
END
ENDIF
STDINFO      7.      310.                    1.       6.       51.
INVYEAR     1986.
DESIGN      20.      300.        3.
SPCODES
119 073 202 017 263 242 108 093 019 122
TREEFMT
(T11,I2,T50,F1.0,T51,I1,T15,A3,T19,F3.1,T52,F1.0,T22,F3.0,T53,2F1.0,T29,
I1,T54,I1,T4,2I1)
OPEN         45.
BEAR01.TREES
TREEDATA     45.
CLOSE        45.
PROCESS
STOP
```

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----

BEAR01   NONE 1986 0100001 310 51 117. 310.
West end of Bear Gulch, Malheur National Forest, Oregon.
      .0000000E+00  .0000000E+00  .0000000E+00  .0000000E+00  .0000000E+00
      .0000000E+00  .4160227E+04  .1248068E+05  .1109394E+05
      .0000000E+00  .3706545E+03  .0000000E+00  .0000000E+00  .0000000E+00
      .0000000E+00  .0000000E+00  .0000000E+00  .6125225E+03  .0000000E+00
      .0000000E+00  .0000000E+00  .0000000E+00  .0000000E+00  .0000000E+00
      .2285308E+03  .0000000E+00  .0000000E+00  .0000000E+00  .0000000E+00
      .2367467E+01
2     .1893874E+02  .7304938E+02  .1231018E+03  .2392032E+03  .4305654E+03
      .1275750E+03  .1862993E+04  .3353386E+04  .9935962E+03
2     .6493280E+01  .4869962E+02  .1055158E+03  .1674420E+03  .3588044E+03
      .2551496E+03  .1117794E+04  .2794490E+04  .1987190E+04
2     .1082213E+01  .3246640E+02  .8792984E+02  .5740872E+02  .2870437E+03
      .2551496E+03  .5588972E+03  .2235590E+04  .1987190E+04
2     .5411066E+00  .8116600E+01  .3517194E+02  .1435218E+02  .3588044E+03
      .6378745E+03  .1862993E+03  .2794490E+04  .4967984E+04
2     .1893874E+02  .7304938E+02  .1231018E+03  .2392032E+03  .4305654E+03
      .1275750E+03  .1862993E+04  .3353386E+04  .9935962E+03
2     .6493280E+01  .4869962E+02  .1055158E+03  .1674420E+03  .3588044E+03
      .2551496E+03  .1117794E+04  .2794490E+04  .1987190E+04
2     .1082213E+01  .3246640E+02  .8792984E+02  .5740872E+02  .2870437E+03
      .2551496E+03  .5588972E+03  .2235590E+04  .1987190E+04
2     .5411066E+00  .8116600E+01  .3517194E+02  .1435218E+02  .3588044E+03
      .6378745E+03  .1862993E+03  .2794490E+04  .4967984E+04
2     .8548     .8548     .8548   1.6051   1.6051   1.6051   3.0789   3.0789   3.0789
2    2.5474    1.6927     .8380   7.9613   6.3564   4.7514  15.7447  12.6662   9.5876
2    1.0000    1.0000    1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000
2    1.0000    1.0000    1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000
2    1.0000    1.0000    1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000
2    1.0000    1.0000    1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000
7     .0000     .0000     .0000    .0000    .0000    .0000   2.3695   2.3695   2.3695
7     .0000     .0000     .0000    .0000    .0000    .0000  34.3572  31.9880  29.6187
```

Figure A-2—Listing of file BEAR01.WRITEFOL. This file is used in example 2, below, along with similar files BEAR02.WRITEFOL and BEAR03.WRITEFOL. The latter two files are not shown. The format of this file is listed in appendix B.

Example A-4: Using the Budworm Dynamics Model

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----

COMMENT
-------------------------------------------------------------------------------
Request that several output tables be printed.  FLYUNIT is used to signal
the program that all of the following stands are included in the dispersal
area.  STNDLOCS is used to enter the sizes and locations of the stands.
-------------------------------------------------------------------------------
END
FALSPR
POPSUM
FLYSUM
INCOND
FLYUNIT
STNDLOCS
BEAR01          18.         .4          .3
BEAR02          32.         1.          .6
BEAR03          18.         1.5         .8
-999
COMMENT
-------------------------------------------------------------------------------
Open file BEAR01.WRITEFOL and then use the ADDSTAND keyword to enter the
foliage data.  Although not used in this example, other stand specific
keywords could be entered between ADDSTAND and END.   ADDSTAND—END groups
are used to enter data for BEAR02 AND BEAR03.
COMMENT
-------------------------------------------------------------------------------
END
OPEN            22.                     2.
BEAR01.WRITEFOL
ADDSTAND        22.
END
CLOSE           22.
OPEN            22.                     2.
BEAR02.WRITEFOL
ADDSTAND        22.
END
CLOSE           22.
OPEN            22.                     2.
BEAR03.WRITEFOL
ADDSTAND        22.
END
CLOSE           22.
COMMENT
-------------------------------------------------------------------------------
PROJECT the three stand run until the year 2000.  The starting year is the
year corresponding to the year the WRITEFOL option for each stand was executed.
-------------------------------------------------------------------------------
END
PROJECT         2000.
STOP
```

APPENDIX B: MACHINE READABLE FILE RECORD FORMATS

The Budworm Model is capable of writing information to external files for processing by statistical analysis and graphics programs. The STATDATA keyword triggers machine-readable output. There are four STATDATA files generated by the Budworm Model:

Biomass: Information about the stand's foliage biomass.

Insect: Information about the insect population in the stands. These data are available only when you are running a version of the Budworm Modeling System that includes population dynamics.

Annual damage: Information on budworm-caused defoliation rates relative to growth rates for budworm model trees.

Periodic damage: Information on growth reduction, topkill, and tree mortality rates. These data are available only when you are running a version of the Budworm Modeling system that includes the Prognosis Model.

Adult dispersal: Information on the gross amount of foliage biomass in each stand, potential eggs originating in the stand, and the post-dispersal egg mass density.

All of the STATDATA files are formatted. They have a common format for columns 1-18; after column 18, the formats differ depending on the value of the STATDATA identifier found in column 2. Table B-1 contains the data formats.

Table B-1—Formats of the STATDATA records

Columns	Data type	FORTRAN format specification	Description
- - - - - - - - - - - - - - - - - - these definitions apply to all STATDATA records -			
1-2	Integer	I2	STATDATA identifier: 1=foliage, 2= insect, 3=annual damage, 4=periodic damage, and 5=adult dispersal.
3-10	Character	A8	Stand identification.
11-14	Character	A4	Management identification.
15-18	Integer	I4	Year.
- - - - - - - - when columns 1-2 are 1=foliage, 2=insect, or 3=annual damage, these definitions apply - - - - - - - -			
19-22	Character	A4	Season: FALL=fall, SPRG=spring, and SUMR=summer.
23-24	Character	A2	Host: WF=white fir, DF=Douglas-fir, GF=grand fir, AF=subalpine fir, ES= Engelmann spruce, and TO=all hosts.
25-28	Character	A4	Tree size: SMAL=small, MED=medium, LARG=large, and TOT=total over tree sizes.
29-32	Character	A4	Crown level: TOP=top crown, MID=midcrown, BOT=bottom crown, and TREE= all crowns.
33-38	Real	F6.1	Trees per hectare.

(con.)

Columns	Data type	FORTRAN format specification	Description
--- when columns 1-2 are 1=foliage, the following apply ---			
39-48	Real	E10.4	Grams/tree of new buds
49-58	Real	E10.4	Grams/tree of remaining foliage
59-68	Real	E10.4	Grams/tree of total foliage
69-82	Real	E14.7	Grams/tree new adjusted potential
83-96	Real	E14.7	Grams/tree total adjusted potential
--- when columns 1-2 are 2=insect, the following apply ---			
39-46	Real	E8.3	Number of adults/tree
47-54	Real	E8.3	Number of L4's/tree
55-62	Real	E8.3	Number of eggs/tree
63-70	Real	E8.3	Number of budworm/tree killed by dispersal
71-78	Real	E8.3	Number of budworm/tree killed by birds
79-86	Real	E8.3	Number of budworm/tree killed by ants
87-94	Real	E8.3	Number of budworm/tree killed by type 1 parasites
95-102	Real	E8.3	Number of budworm/tree killed by type 2 parasites
103-110	Real	E8.3	Number of budworm/tree killed by foliage quality
111-118	Real	E8.3	Number of budworm/tree killed by spraying
--- when columns 1-2 are 3=annual damage, the following apply ---			
29-38			Blank
39-48	Real	F10.3	Proportion new-foliage defoliated over top third
49-58	Real	F10.3	Proportion new-foliage defoliated over whole tree
59-65	Real	F7.3	Proportion of Expected Diameter Growth
66-72	Real	F7.3	Proportion of Expected Height Growth
73-79	Real	F7.3	Maximum 5-yr cumulative defoliation percent (range is 0 to 500)
80-86	Real	F7.3	Maximum average new-foliage defoliation over top third
--- when columns 1-2 are 4=periodic damage, the following apply ---			
19-23	Integer	I5	Prognosis Model tree number
25-27	Character	A3	Prognosis Model tree species and value class
28-34	Real	F7.2	Prognosis Model tree diameter breast height (inches)
35-41	Real	F7.2	Prognosis Model tree height (feet)
41-49	Real	F8.3	Prognosis Model trees per acre
50-57	Real	F8.3	Prognosis Model estimate of mortality in trees per acre
58-65	Real	F8.3	Estimate of mortality used by the combined models in trees per acre
66-72	Real	F7.3	Prognosis Model estimate of diameter growth in inches
73-79	Real	F7.3	Estimate of diameter growth used by the combined models in inches
80-86	Real	F7.3	Prognosis Model estimate of height growth in feet
87-93	Real	F7.3	Estimate of height growth used by the combined models in feet
94-100	Real	F7.3	Probability of top kill
101-107	Real	F7.1	Amount of top actually killed in feet

(con.)

Table B-1 (Con.)

Columns	Data type	FORTRAN format specification	Description
--------- when columns 1-2 are 5=adult dispersal, the following apply ---------			
19-21	Character	A3	NET=net adult dispersal option is used SIM=adult dispersal is simulated.
22-32	Real	E11.4	Gross host foliage in m²/ha
33-43	Real	E11.4	Number of potential eggs/ha prior to dispersal
44-54	Real	E11.4	Number of eggs laid after dispersal in eggs/ha
55-65	Real	E11.4	Final post-dispersal egg mass density in egg masses/m² of foliage

The Prognosis-Budworm Dynamics Model can write a file of foliage and stand descriptions useful in the Budworm Dynamics Model. This file is created when you use the WRITEFOL keyword and the contents are tabulated in table B-2.

Table B-2—Format of the WRITEFOL file

Columns	Data type	FORTRAN format specification	Description
-------------------------------- record 1, header record --------------------------------			
2-9	Character	A8	Stand identification
11-14	Character	A4	Management identification
16-19	Integer	I4	Year this file represents in time
21-27	Integer	7I1	An array of 7 flags. If a member is 1, the corresponding species is present; if the member is 0, the species is absent. In figure A-2, species 2 and 7 are present and the others are absent.
29-31	Integer	I3	Habitat type code of the stand
33-34	Integer	I2	Stand elevation in hundreds of feet
35-39	Real	F5.0	Stand basal area (ft²/acre)
40-44	Real	F5.0	Maximum basal area for the site (ft²/acre)
-------------------------------- record 2, identification record --------------------------------			
2-73	Character	A72	Run identification or title
-------------------------------- records 3-4, non-host foliage --------------------------------			
3-16	Real	E14.7	Nine values of non-host foliage
17-30	Real	E14.7	biomass, one value for each of the
31-44	Real	E14.7	nine classes (table 4). Units are
45-58	Real	E14.7	grams/ha, dry weight.
59-72	Real	E14.7	

(con.)

Table B-2 (Con.)

Columns	Data type	FORTRAN format specification	Description
--------------------------- records 5-9, trees per hectare ---------------------------
3-16	Real	E14.7	Number of trees/hectare for each of three
17-30	Real	E14.7	tree size classes (small, medium, large),
31-44	Real	E14.7	and seven species for a total of 21 values.
45-58	Real	E14.7	
59-72	Real	E14.7	
------------------------------ records 10-26, foliage-------------------------------
2	Integer	I2	Species code
3-16	Real	E14.7	Nine values of host foliage for one species.
17-30	Real	E14.7	The first four couplets of records are for
31-44	Real	E14.7	potential new, 1-yr-old, 2-yr-old, and
45-58	Real	E14.7	remaining potential foliage. The next four
59-72	Real	E14.7	couplets are for adjusted potential foliage.
-------------------------- records 27-28, crown length and height ----------------------
2	Integer	I2	Species code
3-10	Real	F8.4	Nine values of crown class length,
11-18	Real	F8.4	for each species; followed by nine
19-26	Real	F8.4	values of crown class height, each
27-34	Real	F8.4	measurement is in meters
35-42	Real	F8.4	
43-50	Real	F8.4	
51-58	Real	F8.4	
59-66	Real	F8.4	
67-74	Real	F8.4	
----------------------- records 29-32, proportion retained biomass ---------------------
2	Integer	I2	Species code
3-10	Real	F8.4	Nine values proportion retain biomass
11-18	Real	F8.4	of new foliage, 1-yr-old, 2-yr-old, and
19-26	Real	F8.4	remaining
27-34	Real	F8.4	
35-42	Real	F8.4	
43-50	Real	F8.4	
51-58	Real	F8.4	
59-66	Real	F8.4	
67-74	Real	F8.4	
--------------------- records 33-34, non-host crown length and height ------------------
2	Integer	I2	Species code
3-10	Real	F8.4	Nine values of crown class length,
11-18	Real	F8.4	for non-host; followed by nine values
19-26	Real	F8.4	of crown class height, each measurement
27-34	Real	F8.4	is in meters
35-42	Real	F8.4	
43-50	Real	F8.4	
51-58	Real	F8.4	
59-66	Real	F8.4	
67-74	Real	F8.4	

APPENDIX C: KEYWORD SUMMARY

The following alphabetical list contains all keywords discussed in this user's guide. The keywords that control various options within the Weather Model are described by Kemp and others (1989). This listing is designed to serve as an index to the keywords and as a quick reference to the parameters to those who remember the name of the keyword they want to use, but not the order and content of the parameter fields. The numbers in parentheses are page numbers in the main text where a detailed explanation of the keyword can be found.

ADDSTAND (23) Add one stand for processing by the Budworm Model.

    field 1:   Data set reference number (no default).

ANTHT (38) Change boundary used to distribute total budworm mortality from ant predation between canopy layers.

    field 1:   Boundary between the upper and middle stand canopy strata in meters; default = 10.0.

    field 2:   Boundary between the lower and middle stand canopy strata in meters; default = 7.0.

ANTSURV (38) Budworm survival rate from ants during each 20-degree-day interval for three stand canopy strata.

    field 1:   Budworm survival rate from ants in the top canopy stratum; default = 1.00.

    field 2:   The middle canopy stratum; default = 0.9968.

    field 3:   The bottom canopy stratum; default = 0.9932.

AVEGGD (26) Specify the average egg density (egg masses per square meter) on the midcrowns of the medium-sized budworm model trees at the beginning of the simulation. Default = 5.0 egg masses per square meter for all hosts.

    field 1:   Year this option is to be scheduled in the Prognosis-Budworm Model (default = 1.0). This field is ignored by the Budworm Dynamics Model.

    field 2:   Masses per square meter on midcrowns of medium-sized white fir.

    field 3:   Masses per square meter on midcrowns of medium-sized Douglas-fir.

    field 4:   Masses per square meter on midcrowns of medium-sized grand fir.

    field 5:   Masses per square meter on midcrowns of medium-sized subalpine fir.

    field 6:   Masses per square meter on midcrowns of medium-sized Engelmann spruce.

BACKFEED (36) Specify the proportion of larvae by host tree species that feed on older foliage rather than disperse when new foliage is not available. Default values can be found in table 9. This is an all-stand keyword.

    field 1:   Numeric species code; required, table 3.

    field 2:   Proportion of second-instar larvae that backfeed.

    field 3:   Proportion of third-instar larvae that backfeed.

	field 4: Proportion of fourth-instar larvae that backfeed.
	field 5: Proportion of fifth-instar larvae that backfeed.
	field 6: Proportion of sixth-instar larvae that backfeed.
BIRDDEN (39)	Change the biomass per hectare (grams per hectare) of each bird guild for each stand successional stage. See table 11 for default values.
	field 1: Stand successional stage index. Enter 1. for grass-shrub stage, 2. for shrub-tree stage, 3. for seral-tree stage, or 4. for old-growth stage (default = 1).
	field 2: Biomass per hectare of guild 1: ground foragers.
	field 3: Biomass per hectare of guild 2: shrub gleaners.
	field 4: Biomass per hectare of guild 3: flockers.
	field 5: Biomass per hectare of guild 4: foliage gleaners.
	field 6: Biomass per hectare of guild 5: flycatchers.
BIRDHRS (39)	Number of foraging hours per day for birds in all guilds.
	field 1: Foraging hours per day; default = 16.0.
BIRDHT (39)	Change boundary used to distribute total budworm mortality from bird predation between upper canopy (40 percent) and lower canopy (60 percent).
	field 1: boundary between two stand canopy strata in meters; default = 10.0.
BIRDMULT (39)	Number of birds represented by each recorded bird in surveys (includes nestlings, nonsinging males, etc.).
	field 1: Bird multiplier; default = 2.5.
BUDKILL (43)	Specify the minimum percentage of defoliation and maximum percentage of shoot expansion allowed when bud killing occurs.
	field 1: Percentage defoliation allowed when bud killing occurs; default = 30.
	field 2: Percentage shoot expansion allowed when bud killing occurs; default = 5.
BUDRATIO (32)	Ratio of reproductive buds to vegetative buds for each host species in grams per shoot. This is an all-stand keyword.
	field 1: Numeric tree species code; required, table 3.
	field 2: Ratio for upper crowns of small trees, default = 0.53.
	field 3: Ratio for midcrowns of small trees, default = 0.00.
	field 4: Ratio for lower crowns of small trees, default = 0.00.
	field 5: Ratio for crowns of medium trees, default = 2.10.
	field 6: Ratio for midcrowns of medium trees, default = 1.05.
	field 7: Ratio for lower crowns of medium trees, default = 0.53.
	Supplemental data record:
	cols 1-10: Ratio for upper crowns of large trees, default = 2.10.
	cols 11-20: Ratio for the midcrowns of large trees, default = 1.05.
	cols 21-30: Ratio for the lower crowns of large trees, default = 0.53.

BWHITHR
(41)

Specify the upper threshold of development for budworms.

field 1: Temperature; default = 37.8 °C (100 °F).

BWLOTHR
(41)

Specify the lower threshold of development for budworms.

field 1: Temperature; default = 5.5 °C (42 °F).

BWSTART
(41)

Specify the Julian day when degree days may start accumulating for budworms.

field 1: Julian date; default = 91 (April 1).

CALLBW
(11)

Schedule a call to the Budworm Model. Several CALLBW keywords may exist for one projection; however, you need specify only one for a budworm projection even if it is scheduled to last longer than the length of a cycle.

field 1: The year you want the Budworm Model called (default = 1).

field 2: The maximum number of years the model will be allowed to run (default = 10).

CLOSE
(6)

field 1: Data set reference number to close.

COMMENT
(6)

Enter comments on supplemental data records that follow this keyword. END the comments with a record that contains END in the first 3 columns.

CONVNEW
(47)

Instar-specific conversion rate for new foliage biomass (grams) consumed (dry weight) to female biomass (grams) gain (dry weight) for each host species. Default values can be found in table 18. This is an all-stand keyword.

field 1: Numeric species code; required, table 3.

field 2: Second-instar conversion rate.

field 3: Third-instar conversion rate.

field 4: Fourth-instar conversion rate.

field 5: Fifth-instar conversion rate.

field 6: Sixth-instar conversion rate.

CONVOLD
(48)

Instar-specific conversion rate for older foliage biomass (grams) consumed (dry weight) to female biomass (grams) gain (dry weight) for each host species. Default values can be found in table 18. This is an all-stand keyword.

field 1: Numeric species code; required, table 3.

field 2: Second-instar conversion rate.

field 3: Third-instar conversion rate.

field 4: Fourth-instar conversion rate.

field 5: Fifth-instar conversion rate.

field 6: Sixth-instar conversion rate.

DAMAGE
(17)

Print cumulative summary (figure 5) of the results of budworm defoliation on hosts foreach stand. NODAMAGE cancels this output.

DEBUG
(22)

Activate debug output for the Budworm Model. NODEBUG deactivates debug output.

DEFOL
(7)

Enter defoliation by year, host species, crown third level (foliage cell), and foliage age class.

field 1: The year of defoliation; default is year 1.

field 2: Numeric species code, see table 3; default is all host species.

field 3: Foliage cell numeric code from table 4; in addition code 10 may be used to signify all foliage cells in small trees, code 11 for medium trees, code 12 for large trees, code 13 for the tops of all tree sizes, code 14 for middle crowns, code 15 for the bottom crowns. Default is all foliage cells.

field 4: Percentage new foliage defoliated; default = 0 percent.

field 5: Percentage 1-year-old foliage defoliated; default = 0 percent.

field 6: Percentage 2-year-old foliage defoliated; default = 0 percent.

field 7: Percentage remaining (3 years and older) foliage defoliated; default = 0 percent.

DETFOL
(15)

Print detailed host foliage data output (see the section "Population Dynamics" and fig. 4). NODETFOL suppresses this output and is the default.

field 1: The number of 20-degree-day intervals between detailed output of current model conditions; default = 1 (produces large volume of output).

DETPOP
(20)

Print detailed budworm population data output for each stand each year. NODETPOP turns off this output.

field 1: The number of 20-degree-day intervals between detailed output of current model conditions; default = 1.

DIRWT
(35)

Weight given instar-specific directional preference versus foliage biomass per crown third(foliage cell) when calculating dispersal destination.

field 1: Use directional preference (1.0) or foliage biomass per foliage cell (0.0) or some combination of the two schemes; default = 0.50; must be between 0.0 and 1.0.

DISNET
(37)

Select a survival rate for dispersing adult females (potential eggs) in this stand when using the net dispersal option.

field 1: Year to schedule this option in the Prognosis-Budworm Model (default = cycle 1).

field 2: Net survival rate; default = 0.8 (80 percent of the potential eggs survive the effects of adult dispersal).

DISPDIR
(36)

Proportion of dispersing larvae will travel in a particular direction by instar. Default values are contained in table 8.

field 1: Instar numeric code as shown in table 8, no default.

field 2: Proportion of budworms that will disperse by moving down.

63

	field 3: Proportion of budworms that will disperse by moving in a lateral direction.
	field 4: Proportion of budworms that will disperse by moving up.
DISPNFOL (36)	Parameters for the relationship between total foliage below and lateral to the original crown level of dispersing larvae and proportion of those larvae that are killed because they land on nonfoliage.
	field 1: Lower asymptote; default = 0.05.
	field 2: Intercept; default = 0.75.
	field 3: Exponential function slope = –0.0000006.
EFFICACY (29)	Specify mortality rates to be simulated when an insecticide is applied by life stage and sex. Default values for fields 3-7 are 0.91 for all instars and both sexes. Specify separate EFFICACY keywords for each sex
	field 1: The year this keyword will take effect; default = 1. This field is ignored by the Budworm Dynamics Model.
	field 2: Budworm sex class; (1 = male, 2 = female); default = 2.
	field 3: Proportion of second-instar budworms (of sex identified in field 2) that are killed by insecticide applications.
	field 4: Proportion of third-instar budworms (of sex identified in field 2) that are killed by insecticide applications.
	field 5: Proportion of fourth-instar budworms (of sex identified in field 2) that are killed by insecticide applications.
	field 6: Proportion of fifth-instar budworms (of sex identified in field 2) that are killed by insecticide applications.
	field 7: Proportion of sixth-instar budworms (of sex identified in field 2) that are killed by insecticide applications.
EGGNONV (38)	field 1: Proportion of budworm eggs that are nonviable; default = 0.054.
EGGPARA (38)	field 1: Egg parasitization rate; default = 0.25.
EGGPMASS (34)	Controls the number of eggs per egg mass.
	field 1: Number of eggs per egg mass laid by adult female budworms; default = 40.1.
EMERGPAT (41)	Specify the temporal pattern of second-instar budworm emergence from hibernacula. It is assumed that emergence can occur over a period of up to fifteen 20-degree-day steps each spring.
	field 1: Proportion emerging during interval 1; default = 0.01.
	field 2: Proportion emerging during interval 2; default = 0.12.
	field 3: Proportion emerging during interval 3; default = 0.20.
	field 4: Proportion emerging during interval 4; default = 0.21.
	field 5: Proportion emerging during interval 5; default = 0.18.
	field 6: Proportion emerging during interval 6; default = 0.11.
	field 7: Proportion emerging during interval 7; default = 0.07.

Supplemental data record:

cols 1-11: Proportion emerging during interval 8; default = 0.04.

cols 11-20: Proportion emerging during interval 9; default = 0.03.

cols 21-30: Proportion emerging during interval 10; default = 0.02.

cols 31-40: Proportion emerging during interval 11; default = 0.01.

cols 41-50: Proportion emerging during interval 12; default = 0.00.

cols 51-60: Proportion emerging during interval 13; default = 0.00.

cols 61-70: Proportion emerging during interval 14; default = 0.00.

cols 71-80: Proportion emerging during interval 15; default = 0.00.

END
(5,11, 23)

Signal the end of one stand's input, or the end of Prognosis-Budworm Model keywords,or the end of Weather Model keywords.

ENDFLYU
(33)

Stop adding stands to the dispersal area.

ENDSPRYU
(29)

Stop adding stands to the spray unit.

FALSPR
(19)

Print the fall-spring population summary table (fig. 8) for each stand each year. NOFALSPR suppresses this output.

FEMDEV
(41)

Specify the number of 20-degree-day intervals per life stage for females. The total number of intervals must be less than 50.

field 1: Intervals for second-instar budworm; default for both sexes is five intervals.

field 2: Intervals for third-instar budworm; default for both sexes is three intervals.

field 3: Intervals for fourth-instar budworm; default for both sexes is four intervals.

field 4: Intervals for fifth-instar budworm; default for both sexes is four intervals.

field 5: Intervals for sixth-instar budworm; default for both sexes is six intervals.

field 6: Intervals for pupae; default for both sexes is nine intervals.

FIRSTEGG
(34)

Control simulation of the number of eggs laid by females in their stand of origin.

field 1: Index value; 1 = females lay one egg mass, 2 = females lay a proportion of their total eggs (enter the proportion in field 2); default = 1.

field 2: When the value in field 1 is 2, enter proportion of total eggs that are laid in the stand of origin; default = 0.50.

FLOWMORT
(37)

Specify the proportion of first-instar budworms that die during fall dispersal or during overwintering in hibernacula.

field 1: Proportion of first or second-instar budworms that die during fall dispersal or during overwintering; default = 0.55.

FLYMORT
(37)

Specify the slope and intercept for the relationship between mean host foliage (square meters per hectare) and adult mortality during dispersal.

field 1: Lower asymptote; default = 0.2.

field 2: Intercept; default = 0.75.

field 3: Exponential function slope; default = –0.0002.

FLYRANGE
(34)

The dispersing range of adult female budworm.

field 1: Maximum dispersal distance in kilometers; default = 25.0 km.

FLYSUM
(21)

Print yearly summary of budworm dispersal dynamics (fig. 10). NOFLYSUM cancels yearly summary of budworm dispersal dynamics.

FLYUNIT
(33)

Simulate adult budworm dispersal among all stands following the keyword.

FNEWFEED
(44)

Specify the amount of new foliage (grams) by host tree species consumed by each female budworm larva during a 20-degree-day period. Default values are found in table 13. This is an all-stand keyword.

field 1: Numeric species code; required, table 3.

field 2: Grams of new foliage consumed by second-instar female budworms.

field 3: Grams of new foliage consumed by third-instar female budworms.

field 4: Grams of new foliage consumed by fourth-instar female budworms.

field 5: Grams of new foliage consumed by fifth-instar female budworms.

field 6: Grams of new foliage consumed by sixth-instar female budworms.

FOLDFEED
(44)

Amount of older foliage (grams) by host tree species consumed by each female budworm during a 20-degree-day period. Default values can be found in table 14. This is an all-stand keyword.

field 1: Numeric species code; required, table 3.

field 2: Grams of old foliage consumed by second-instar female budworm.

field 3: Grams of old foliage consumed by third-instar female budworm.

field 4: Grams of old foliage consumed by fourth-instar female budworm.

field 5: Grams of old foliage consumed by fifth-instar female budworm.

field 6: Grams of old foliage consumed by sixth-instar female budworm.

FOLQUAL (40)	Multipliers that represent the effects of foliage quality on budworm survival and weight gain. The multipliers are indexed by habitat series and host species. Default values can be found in table 12. This is an all-stand keyword.
	field 1: Habitat series numeric code, see table 12.
	field 2: Multiplier for foliage quality on white fir.
	field 3: Multiplier for foliage quality on Douglas-fir.
	field 4: Multiplier for foliage quality of grand fir.
	field 5: Multiplier for foliage quality of subalpine fir.
	field 6: Multiplier for foliage quality of Engelmann spruce.
FOLSUM (15)	Print an annual summary of foliage dynamics (fig. 3). NOFOLSUM suppresses this output and is the default.
FWASTEDN (46)	Proportion of total new foliage destroyed that is wasted (clipped but not consumed) by female budworm larvae for each host tree species. Default values can be found in table 17. This is an all-stand keyword.
	field 1: Numeric species code; required, table 3.
	field 2: Proportion wasted by second-instar female budworm.
	field 3: Proportion wasted by third-instar female budworm.
	field 4: Proportion wasted by fourth-instar female budworm.
	field 5: Proportion wasted by fifth-instar female budworm.
	field 6: Proportion wasted by sixth-instar female budworm.
FWASTEDO (46)	Specify the proportion of total older foliage destroyed that is wasted (clipped but not consumed) by female budworm larvae for each host tree species. Default values can be found in table 17. This is an all-stand keyword.
	field 1: Numeric species code; required, table 3.
	field 2: Proportion wasted by second-instar female budworm.
	field 3: Proportion wasted by third-instar female budworm.
	field 4: Proportion wasted by fourth-instar female budworm.
	field 5: Proportion wasted by fifth-instar female budworm.
	field 6: Proportion wasted by sixth-instar female budworm.
GPERM2 (32)	Factor to convert grams of foliage biomass to foliage surface area. For a given host and crown level, the same values are used for each tree size class. Default values are given in table 7. This is an all-stand keyword.
	field 1: Numeric tree species codes; required, table 3.
	field 2: Grams per square meter foliage for the upper crowns of small trees.
	field 3: Grams per square meter foliage for the midcrowns of small trees.
	field 4: Grams per square meter foliage for the lower crowns of small trees.
	field 5: Grams per square meter foliage for the upper crowns of medium trees.

field 6: Grams per square meter foliage for the midcrowns of medium trees.

field 7: Grams per square meter foliage for the lower crowns of medium trees.

Supplemental data record:

cols 1-10: Grams per square meter foliage for the upper crowns of large trees.

cols 11-20: Grams per square meter foliage for the midcrowns of large trees.

cols 21-30: Grams per square meter foliage for the lower crowns of large trees.

HIDEBUD
(43)
Specify the proportion of buds that are effectively hidden (protected from mining) frombudworms during a given 20-degree-day interval.

field 1: Proportion of hidden buds during any time step; default = 0.10.

HIDEBW
(40)
field 1: The proportion of the budworm population that is effectively hidden from predators and parasites each 20-degree-day step; default = 0.10.

HIDEFOL
(43)
Specify the proportion of foliage that is effectively hidden from budworm during each 20-degree-day interval.

field 1: Proportion of hidden foliage during any time step; default = 0.10.

HOSTART
(42)
Specify the Julian day when degree days may start accumulating for budworm hosts; all defaults = 121 (May 1).

field 1: Julian date for white fir.

field 2: Julian date for Douglas-fir.

field 3: Julian date for grand fir.

field 4: Julian date for subalpine fir.

field 5: Julian date for Engelmann spruce.

HOSTHIGH
(42)
Specify the upper development threshold for hosts. All defaults = 35 °C (95 °F).

field 1: Temperature for white fir.

field 2: Temperature for Douglas-fir.

field 3: Temperature for grand fir.

field 4: Temperature for subalpine fir.

field 5: Temperature for Engelmann spruce.

HOSTLOW
(42)
Specify the lower development threshold for hosts. All defaults = 5.5 °C (42 °F).

field 1: Temperature for white fir.

field 2: Temperature for Douglas-fir.

field 3: Temperature for grand fir.

field 4: Temperature for subalpine fir.
field 5: Temperature for Engelmann spruce.

IMMDISP (35)	field 1:	Enter the proportion of L2's that disperse immediately after they leave their hibernaculae; default = 0.80.
INCOND (14)		Request that the initial conditions be displayed.
L2DISP (35)	field 1:	Specify the proportion of emerging second-instar budworm that disperse rather than mine needles if they cannot find buds; default = 0.50.

MALEDEV (41)

Specify the number of 20-degree-day intervals per life stage for males. The total number of intervals must be less than 50.

field 1: Intervals for second-instar budworm; default for both sexes is five intervals.

field 2: Intervals for third-instar budworm; default for both sexes is three intervals.

field 3: Intervals for fourth-instar budworm; default for both sexes is three intervals.

field 4: Intervals for fifth-instar budworm; default for both sexes is four intervals.

field 5: Intervals for sixth-instar budworm; default for both sexes is six intervals.

field 6: Intervals for pupae; default for both sexes is nine intervals.

MINDDAY (41)

Specify the minimum number of accumulated degree days required before second-instar budworms emerge from hibernaculae; default = 68.

MNEWFEED (45)

Specify the amount of new foliage (grams) by host tree species consumed by each male budworm larva during a 20-degree-day period. Default values can be found in table 15. This is an all-stand keyword.

field 1: Numeric species code; required, table 3.

field 2: Grams consumed by second-instar male budworm.

field 3: Grams consumed by third-instar male budworm.

field 4: Grams consumed by fourth-instar male budworm.

field 5: Grams consumed by fifth-instar male budworm.

field 6: Grams consumed by sixth-instar male budworm.

MOLDFEED (45)

Specify the amount of older foliage (grams) by host tree species consumed by each male budworm during a 20-degree-day period. Default values can be found in table 16. This is an all-stand keyword.

field 1: Numeric species code; required, table 3.

field 2: Grams consumed by second-instar male budworm.

field 3: Grams consumed by third-instar male budworm.

field 4: Grams consumed by fourth-instar male budworm.

field 5: Grams consumed by fifth-instar male budworm.

field 6: Grams consumed by sixth-instar male budworm.

MWASTEDN
(47)

Specify the proportion of total new foliage destroyed that is wasted (clipped but not consumed) by male budworm larvae for each host tree species. Default values can be found in table 17. This is an all-stand keyword.

field 1: Numeric species code; required, table 3.

field 2: Proportion destroyed that is wasted by second-instar male budworm.

field 3: Proportion destroyed that is wasted by third-instar male budworm.

field 4: Proportion destroyed that is wasted by fourth-instar male budworm.

field 5: Proportion destroyed that is wasted by fifth-instar male budworm.

field 6: Proportion destroyed that is wasted by sixth-instar male budworm.

MWASTEDO
(47)

Specify the proportion of total older foliage destroyed that is wasted (clipped but not consumed) by male budworm larvae for each host species. Default values can be found in table 17. This is an all-stand keyword.

field 1: Numeric species code; required, table 3.

field 2: Proportion destroyed that is wasted by second-instar male budworm.

field 3: Proportion destroyed that is wasted by third-instar male budworm.

field 4: Proportion destroyed that is wasted by fourth-instar male budworm.

field 5: Proportion destroyed that is wasted by fifth-instar male budworm.

field 6: Proportion destroyed that is wasted by sixth-instar male budworm.

NEEDLMAS
(32)

Potential biomass per needle when fully expanded for each host in the absence of budworm feeding. This is an all-stand keyword.

field 1: Grams per needle for white fir; default = 0.013.

field 2: Grams per needle for Douglas-fir; default = 0.005.

field 3: Grams per needle for grand fir; default = 0.009.

field 4: Grams per needle for subalpine fir; default = 0.009.

field 5: Grams per needle for Engelmann spruce; default = 0.005.

NOSPRAY
(28)

Turn off possibility of insecticide application.

field 1: Year the possibility of spraying is turned off.

NOTOPKIL
(9)

Turn off Prognosis-Budworm Model topkill calculations.

OPEN
(5)

A FORTRAN file OPEN is requested using this keyword. The file name is entered on a supplemental record.

field 1: Data set reference number (or UNIT) to open; no default.

field 2: Enter a nonzero value if blanks in the data set are to be treated as NULL characters. Enter a blank field or a zero (which is the default) to signify that blanks be treated as zeros when the file is read for numeric data.

field 3: Enter a code for the file status: 0 (or leave the field blank) for UNKNOWN, 1 for NEW, and 2 for OLD.

field 4: The MAXRECL parameter for Data General computers or the MRECL parameter on Unisys computers; default is 80 characters.

Supplemental data record:

Cols 1-80: Enter the data set name with no leading blanks.

PERDAM
(17)
Print periodic table that displays (fig. 6) the results of budworm defoliation on Prognosis Model trees. NOPERDAM cancels the output.

POPSUM
(19)
Print an annual summary (fig. 7) of population dynamics for each stand. NOPOPSUM suppresses this output.

PREDMORT
(22)
Activate predator output (no example is illustrated).

PROJECT
(23)
Signal the Budworm Model to run the projection. If no stands have been added (see ADDSTAND above), the model stops.

field 1: The year you want the simulation to stop (default is 1 year after the current STARTYR).

PROPMATE
(34)
Specify the proportion of emerging females that will mate and bear eggs. May be used to simulate the effects of mating disruption.

field 1: Proportion of females mated; default = 1.0.

RANNSEED
(6)
field 1: New random number generator seed; default = 55329. If you enter 0.0, a seed will be generated by calling the computer system clock.

REGGDEN
(26)
Relative egg mass densities to be used to determine egg densities per foliage cell. All values are based on differences between egg mass densities in the crowns of medium trees. Default values can be found in table 5. This is an all-stand keyword.

field 1: Numeric tree species code; required, table 3.

field 2: Relative densities in the upper crowns of small trees.

field 3: Relative densities in the midcrowns of small trees.

field 4: Relative densities in the lower crowns of small trees.

field 5: Relative densities in the upper crowns of medium trees.

field 6: Relative densities in the midcrowns of medium trees

field 7: Relative densities in the lower crowns of medium trees.

Supplemental data record:

cols 1-10: Relative densities in the upper crowns of large trees.

cols 11-20: Relative densities in the midcrowns of large trees.

cols 21-30: Relative densities in the lower crowns of large trees.

RELL2DEN
(34)
Relative densities of emerging second instars by crown level and host.

field 1: Numeric species code; required, table 3.

field 2: Relative densities in the upper crowns of small trees. Default for all tree species is 0.440.

field 3: Relative densities in the midcrowns of small trees. Default for all tree species is 0.316.

field 4: Relative densities in the lower crowns of small trees. Default for all tree species is 0.243.

field 5: Relative densities in the upper crowns of medium trees. Default for all tree species is 0.440.

field 6: Relative densities in the midcrowns of medium trees. Default for all tree species is 0.316.

field 7: Relative densities in the lower crowns of medium trees. Default for all tree species is 0.243.

Supplemental Data Record:

cols 1-10: Relative densities in the upper crowns of large trees. Default for all tree species is 0.440.

cols 11-20: Relative densities in the midcrowns of large trees. Default for all tree species is 0.316.

cols 21-30: Relative densities in the lower crowns of large trees. Default for all tree species is 0.243.

REPRDEV
(43)
Slope and intercept for the relationship between reproductive bud suitability for mining and percentage of shoot expansion of vegetative buds.

field 1: Slope; default = 1.0.

field 2: Intercept; default = 0.0.

RESET
(25)
Recall the default values for all options. If used within an ADDSTAND-END group, this keyword applies only to one stand. Otherwise, this keyword applies to the entire Budworm Model.

REWIND
(6)
field 1: Data set reference number to rewind; no default, an entry is required.

SETPRBIO
(7)
Set the proportion of retained biomass to an inventory time estimate. The data enteredusing SETPRBIO is used to alter the starting foliage biomass values.

field 1: The year that the SETPRBIO is applied.

field 2: Numeric species code, see table 3; default is all host species.

field 3: Foliage cell numeric code from table 4; in addition code 10 may be used to signify all foliage cells in small trees, code 11 for medium trees, code 12 for large trees, code 13 for the tops of all tree sizes, code 14 for middle crowns, code 15 for the bottom crowns. Default is all foliage cells.

field 4: Proportion of 1-year-old foliage retained; default is 1.0, which means 100 percent of the foliage you expected was retained (entering 0.6 means that 40 percent of the foliage was missing).

field 5: Proportion of 2-year-old foliage retained; default is 1.0.

field 6: Proportion of remaining foliage retained; default is 1.0.

	Entering 2.0 means that twice as much foliage is in the remaining age class than you would expect on a healthy tree and implies that the trees responded to defoliation by retaining old needles.
SHOOTMAS (31)	Potential foliage biomass (dry weight) per shoot when fully expanded in the absence of budworm feeding. Default values can be found in table 5. SHOOTMAS is an all-stand keyword.

field 1: Numeric tree species code; required, see table 3.

field 2: Grams per shoot for the upper crowns of small trees.

field 3: Grams per shoot for the midcrowns of small trees.

field 4: Grams per shoot for the lower crowns of small trees.

field 5: Grams per shoot for the upper crowns of medium trees.

field 6: Grams per shoot for the midcrowns of medium trees.

field 7: Grams per shoot for the lower crowns of medium trees.

Supplemental data record:

cols 1-10: Grams per shoot for the upper crowns of large trees.

cols 11-20: Grams per shoot for the midcrowns of large trees.

cols 21-30: Grams per shoot for the lower crowns of large trees.

SPRAY
(28)

Turn on possibility of insecticide application.

field 1: Year when spraying is to be allowed if conditions described by SPRAYREQ are met.

field 2: Waiting time in years between applications; default is 0.

SPRAYREQ
(28)

Specify the criteria that must be exceeded before insecticide is applied. These criteria are checked for the indicator stand (see SPRYINDC keyword). The Julian day all criteria are met is the spray day for all of the stands. In the Prognosis-Budworm Model, the option only applies to the single stand you are processing.

field 1: The percentage defoliation of the previous year's new foliage defoliation that must be exceeded before spray is applied; default is 50 percent.

field 2: Spring second-instar density per 100 shoots that must be exceeded before spray is applied; default is 10 per 100 shoots.

field 3: Percent shoot elongation that must be exceeded before spray is applied; default is 10 percent.

field 4: Average life stage of the budworm population that must be exceeded before spray is applied; default is 4.0, which means that the average instar is fourth instar.

SPRMORT
(37)

Enter a net spring mortality rate to account for spring dispersal to initial feeding sites. Further dispersal mortality will occur as feeding larvae move between foliage cells (crown thirds and trees).

field 1: Proportion of second-instar budworm that die during spring dispersal to feeding sites; default = 0.30.

SPRYINDC
(29)

Identify the indicator stand by placing this keyword inside the ADDSTAND—END group that should serve as the indicator stand.

SPRYUNIT
(29)

All of the stands that follow this keyword will be sprayed as a block. This is an all-stand keyword. Only one block can be designated during a run.

STARTYR
(23)

Enter the first year of the projection period.

field 1: The starting date of the projection (default is the year the foliage was generated using the WRITEFOL keyword for the first stand encountered).

STATDATA
(21)

Creates machine-readable output files of yearly foliage and population variables.

field 1: Data set reference number for foliage biomass output; if blank, these data are not written.

field 2: Data set reference number for population output; if blank, these data are not written.

field 3: Data set reference number for annual damage output; if blank, these data are not written.

field 4: Data set reference number for periodic damage output; if blank, these data are not written.

field 5: Data set reference number for adult dispersal output; if blank, these data are not written.

STNDLOCS
(27)

Read in stand locations and sizes. This is an all-stand keyword.

field 1: Dataset reference number for stand location records; default is the same file used to read keywords.

field 2: A multiplier used to scale area data to hectares; default is 1.0.

field 3: A multiplier used to scale location data to kilometers; default is 1.0.

Supplemental data records:

cols 1-8: Stand identification code used to identify the stand in the Prognosis Model via the STDIDENT keyword.

cols 11-20: Stand area (see field 2).

cols 21-30: X-coordinate for stand centroid (see field 3).

cols 31-40: Y-coordinate for stand centroid (see field 3).

STOP
(23)

Stop the model.

TOPKILL
(9)

Activate the Prognosis-Budworm Model's topkill logic (the default); or turn it off.

TOTEGG
(26)

Specify the total number of western spruce budworm eggs per hectare for a stand at the beginning of a simulation. Default = 50.0 (50,000) eggs per hectare.

field 1: Year this option is to be scheduled in the Prognosis-Budworm Model (default year = 1.0). This field is ignored by the Budworm Dynamics Model.

field 2: Total number of budworms per hectare for this stand multiplied by 1,000.

USEFOLQ (40)	Turn on the used of values found in table 12.
	field 1: Apply FOLQUAL values to weight gain calculations if any numeric value is entered.
	field 2: Apply FOLQUAL values to survival calculations if any numeric value is entered.
VEGDEV (43)	Specify the slope and intercept of the relationship between proportion of average vegetative bud development and bud availability for budworm mining (proportion of bud population that are available for mining).
	field 1: Slope; default = 1.0.
	field 2: Intercept; default = 0.0.
WEATHER (11)	Signals Weather Model keywords follow.
WRITEFOL (10)	Request that a file of Budworm Model foliage conditions be written for the stand.
	field 1: The year during the projection that the file is to be written; default = 1.
	field 2: The data set reference number.
WRTDEFOL (21)	Generate a file of DETFOL keywords.
	field 1: The data set reference number for the output. If a zero is entered no DETFOL keywords are written.
WSBW (5)	Signals the beginning of Prognosis-Budworm Dynamics Model keywords.

The Budworm Modeling System is a set of four computer programs: The Budworm Dynamics Model, the Prognosis-Budworm Dynamics Model, the Prognosis-Budworm Damage Model, and the Parallel Processing-Budworm Dynamics Model. Input to the first three programs and the output produced are described in this guide. A guide to the fourth program will be published separately. Publications regarding the programs' purpose, general structure, and scientific basis are listed. The modeling system is useful for studying and managing budworm-infested forests.

KEYWORDS: *Choristoneura occidentalis* Freeman, simulation, pest management

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